WEED CONTROL IN U.S. RICE PRODUCTION

Agriculture Handbook No. 497

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
in cooperation with
Arkansas, California, and Texas Agricultural Experiment Stations

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This handbook supersedes Agriculture Handbook No. 292, "Weeds and Their Control in Rice Production," by R. J. Smith, Jr., and W. C. Shaw.

Washington, D.C. Issued March 1977

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $1.50
Stock No. 001-000-03656-4

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THE WEED PROBLEM

Weeds reduce the yield and quality of rice in the United States by an estimated 15 percent each year on approximately 2.5 million acres; this loss is valued at about $165 million. The cost of using herbicides to prevent greater losses was about $55 million in 1974. In the same year the cost of cultural practices (including rotations, land preparation, irrigation, and fertilization), prorated to control weeds, was estimated at $70 million. Thus, the total estimated direct losses from weeds and expenditures for their control are $290 million annually.

Herbicide usage in rice has steadily increased as effective herbicides have been developed. About 81 percent of the commercial rice in the United States was treated with one or more herbicides in 1968, up from 78 percent in 1965 and 53 percent in 1962 (*134, 136, 138*).[1] Since 1968, herbicide usage in rice has continued to increase to where an estimated 95 percent of the acreage was treated in 1974. Custom aerial applicators apply herbicides to 87 percent or more of the rice acreage, while farmers apply the remainder (*138*).

Effective weed control systems combine preventive, cultural, mechanical, chemical, and biological methods. Nonchemical methods may include some or all of the following practices: planting weed-free seed, crop rotation, leveling land, seedbed preparation, selecting the proper seeding method, and managing water and fertilizers properly. Chemical methods involve the use of herbicide treatments that selectively control weeds in rice when applied correctly. The system that omits any one of these components is often inadequate.

In this handbook we emphasize the importance of combining various cultural and chemical practices to effectively control weeds. This handbook is designed as a guide for research scientists, extension specialists, county agents, vocational agricultural teachers, and personnel of private and public organizations concerned with rice production, research, and education in the United States and abroad.

Since the use of herbicides for weed control in rice changes and since new herbicides or new uses for older ones are continually being developed, it is important to obtain the latest information on herbicides before using them. All pesticide products must be registered by the Environmental Protection Agency (EPA) before they can be legally used in the United States. Use of nonregistered pesticides, or use in violation of the directions on the label, is illegal and punishable. Since the status of chemical weed control may change rapidly, it is important to keep in touch with the EPA, the State experiment stations, the cooperative extension services, or manufacturers of specific products for up-to-date information.

Weeds compete with rice for light, nutrients, space, water, and other growth requirements. Experiments in the United States (*107*), Australia (*9*), Japan (*83*), the Philippines (*30*), and Taiwan (*18*) vividly demonstrate that weeds reduce grain yields and lower the market value by reducing quality. Furthermore, weeds increase the cost of production, harvesting, drying, and cleaning, and they increase infestations of other pests by harboring insects and diseases.

Conditions favorable for growing rice are also favorable for the growth and reproduction of many terrestrial, aquatic, and semiaquatic weeds. Weeds in rice produce an abundance of viable seed, and once these seed infest the soil they are difficult to remove and may remain viable in the soil for many years. The broadcast seeding and drill seeding of rice reduce the opportunity for cultivation after emergence to remove weeds.

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[1] Italic numbers in parentheses refer to "Selected References," page 74.

EFFECT OF WEED COMPETITION ON RICE

Field trials with barnyardgrass, hemp sesbania, northern jointvetch, and ducksalad—among the most serious and widely distributed weed pests in rice—have demonstrated that weed competition substantially reduces rice yields. In trials conducted in 1961 chiefly with barnyardgrass (other weed grasses, sedge, broadleaf, and aquatic weeds were present), yields were reduced about 74 percent in Arkansas, 35 percent in Louisiana, 64 percent in Mississippi, 48 percent in Texas, and 36 percent in California (*14*).

Both the density of weeds in rice and the duration of weed-rice competition affect rice yields. In numerous field experiments with various rice varieties, yields decreased with increasing weed density and increasing duration of competition (barnyardgrass, tables 1 and 4; hemp sesbania, tables 2 and 5; northern jointvetch, tables 3 and 6; ducksalad, table 7). Even one barnyardgrass plant in 31 rice plants per square foot reduced yields; moreover, the thinner the stand of rice, the greater the loss in yield (table 1).

Barnyardgrass and ducksalad compete more with rice than hemp sesbania and northern jointvetch during the early growing season (tables 4–6); hemp sesbania and northern jointvetch compete most during the late season by shading the crop.

The seed of such weeds as dayflower, hemp sesbania, northern jointvetch, mexicanweed, and red rice reduce the value of the grain by lowering the market grade. All are difficult to remove. Red rice, which belongs to the same species as white rice, has a red bran coat. When red and white rice grains are mixed, the close milling required to remove the red coat breaks many white rice kernels. Broken rice has less value than whole milled rice. Moreover, if the red bran coat is not entirely removed, the milled rice is unattractive, and its market value is reduced.

Seeds of hemp sesbania, northern jointvetch, and morningglory are not permitted in foundation, registered, and certified rice seed. Red rice seed is not permitted in foundation rice seed, and only a small quantity (0.5 to 1 seed per pound) is allowed in registered and certified seed. The maximum quantity of all weed seed that includes beakrush, dayflower, mexicanweed, and smartweed cannot exceed 0.05 percent in foundation and registered seed or 0.1 percent in certified. Specific standards are es-

TABLE 1.—*Effect of barnyardgrass density on yield of* 'Bluebonnet 50' *rice, Stuttgart, Ark., 1962–1963*[1]

Plants/square foot: Rice	Plants/square foot: Grass	Rough rice yield (lb/acre)	Yield per acre lost to grass competition: Pounds	Percent	Dollar value[2]
3	0	4,460	...	...	...
3	1	1,930	2,530	57	126
3	5	890	3,570	80	178
3	25	240	4,220	95	211
10	0	5,160	...	...	...
10	1	3,110	2,050	40	102
10	5	1,760	3,400	66	170
10	25	580	4,580	89	229
31	0	5,580	...	...	...
31	1	4,190	1,390	25	70
31	5	2,840	2,740	49	137
31	25	1,180	4,400	79	220
LSD (5 pct)[3]		750	...	...	...

[1] Data taken from Smith (*109*). Barnyardgrass competed with rice all season.
[2] Rough rice valued at $5/hundredweight.
[3] LSD = least significant difference at level given.

TABLE 2.—*Effect of hemp sesbania density on yield of* 'Bluebonnet 50', 'Nato', *and* 'Northrose' *rice, Stuttgart, Ark., 1960–62*[1]

Hemp sesbania plants/acre	Rough rice yield (lb/acre)	Yield per acre lost to sesbania competition: Pounds	Percent	Dollar value[2]
0	5,520	...	...	...
5,445	4,970	550	10	28
10,890	4,690	830	15	42
21,780	4,030	1,490	27	74
43,560	3,310	2,210	40	110
LSD (5 pct)[3]	610	610	11	...
LSD (1 pct)[3]	880	880	16	...

[1] Data taken from Smith (*109*). Hemp sesbania competed until rice was mature.
[2] Rough rice valued at $5/hundredweight.
[3] LSD = least significant difference at level given.

TABLE 3.—*Effect of northern jointvetch density on yield of* 'Bluebonnet 50' *and* 'Northrose' *rice, Stuttgart, Ark., 1963–64*[1]

Northern jointvetch plants/acre	Rough rice yield (lb/acre)	Yield per acre lost to jointvetch competition		
		Pounds	Percent	Dollar value[2]
0	6,380	...	...	...
5,445	6,120	260	4	13
10,890	5,930	450	7	22
21,780	5,680	700	11	35
43,560	5,170	1,210	19	60
LSD (5 pct)[3]	510	510	8	...
LSD (1 pct)[3]	760	760	12	...

[1] Data taken from Smith (*109*). Northern jointvetch competed until rice was mature.
[2] Rough rice valued at $5/hundredweight.
[3] LSD = least significant difference at level given.

TABLE 4.—*Yield of* 'Bluebonnet 50' *and* 'Northrose' *rice as influenced by duration of barnyardgrass competition, Stuttgart, Ark., 1962–65*[1]

Duration of competition	Rough rice yield (lb/acre)	Yield per acre lost to grass competition		
		Pounds	Percent	Dollar value[2]
7–10 days	4,900	...	...	...
15–20 days	4,470	430	9	22
22–26 days	4,520	380	8	19
37–40 days	3,920	980	20	49
51–54 days	3,180	1,720	35	86
65–68 days	2,800	2,100	43	105
All season	1,010	3,890	79	194
LSD (5 pct)[3]	400	...	8	...
LSD (1 pct)[3]	540	...	11	...

[1] Data taken from Smith (*109*). Rice contained about 50 barnyardgrass panicles/square foot.
[2] Rough rice valued at $5/hundredweight.
[3] LSD = least significant difference at level given.

TABLE 5.—*Yield of* 'Bluebonnet 50' *and* 'Northrose' *rice as influenced by duration of hemp sesbania competition, Stuttgart, Ark., 1961–62*[1]

Duration of competition	Rough rice yield (lb/acre)	Yield per acre lost to sesbania competition		
		Pounds	Percent	Dollar value[2]
0 (check)	5,710	...	...	...
4 weeks	5,600	110	2	6
8 weeks	5,370	340	6	17
12 weeks	5,200	510	9	26
All season	4,630	1,080	19	54
LSD (5 pct)[3]	460	460	8	...
LSD (1 pct)[3]	630	630	11	...

[1] Data taken from Smith (*109*). Hemp sesbania population was 21,780 plants/acre.
[2] Rough rice valued at $5/hundredweight.
[3] LSD = least significant difference at level given.

TABLE 6.—*Yield of* 'Bluebonnet 50' *and* 'Northrose' *rice as influenced by duration of northern jointvetch competition, Stuttgart, Ark., 1963–64*[1]

Duration of competition	Rough rice yield (lb/acre)	Yield per acre lost to jointvetch competition		
		Pounds	Percent	Dollar value[2]
0 (check)	6,100	...	...	...
4 weeks	5,980	120	2	6
8 weeks	5,610	490	8	24
12 weeks	5,610	490	8	24
All season	5,060	1,040	17	52
LSD (5 pct)[3]	490	490	8	...
LSD (1 pct)[3]	730	730	12	...

[1] Data taken from Smith (*109*). Northern jointvetch population was 21,780 plants/acre.
[2] Rough rice valued at $5/hundredweight.
[3] LSD = least significant difference at level given.

tablished for each State, and a list of these is available from each of the official certifying agencies (*6*).

RICE CULTURE AND WEED PROBLEMS

Rice production in the United States is centered in the Southern States of Arkansas, Louisiana, Mississippi, and Texas and in California. It is the principal cash crop in many counties and parishes. Small amounts of rice also are grown in Missouri, Oklahoma, South Carolina, and Tennessee. Some rice has been grown in each of the States in Southeastern United States. A handbook compiled by the U.S. Department of Agriculture discusses rice production in the United States (*139*).

Algae, grass, and broadleaf and sedge weeds infest ricefields. Both annuals and perennials in terrestrial and aquatic sites are problems in rice culture. Terrestrial weeds germinate in moist soil, and most tolerate flushing after emergence; aquatic weeds germinate and grow in flooded soil. Weed species making up the total weed complex in a field vary among rice-growing regions and areas and often differ between adjacent fields. Methods that control one complex of weeds may fail completely in another field that is infested with a different weed complex.

Several methods are used to seed rice in the United States. Different weed complexes are associated with each seeding method. Rice seeded in soil is usually infested with terrestrial weeds such as barnyardgrass, dayflower, and morningglory that tolerate flooding after emergence; aquatic weeds germinate after flooding, when rice is about 3 weeks old. Rice seeded in water is usually infested with aquatic weeds such as algae, ducksalad, American and horned pondweed, and redstem that germinate in flooded soil; terrestrial weeds may germinate during drained periods after rice emerges. Each weed complex that develops in the various cultures requires a particular weed control program.

DEVELOPMENT OF HERBICIDES AND CHANGES IN RICE CULTURE AND WEED CONTROL PRACTICES

Herbicides are required to control weeds in rice when preventive, cultural, and mechanical methods fail. Combinations of herbicides, in mixtures or in sequential applications, are often more effective than a single treatment with only one herbicide. The principal herbicides in use are propanil, molinate, and the phenoxy herbicides, chiefly 2,4-D, 2,4,5-T, silvex, and MCPA. In 1973 about 95 percent of the U.S. rice crop was treated with propanil or molinate to control grass and broadleaf and sedge weeds; about 30 percent was sprayed with phenoxy herbicides to control aquatic, broadleaf, and sedge weeds (table 8).

Propanil has increasingly replaced the phenoxy herbicides. The first experiments in Arkansas in 1959 showed that propanil controlled certain young grasses and broadleaf weeds in rice. It was very selective, and early postemergence treatments at high rates of 8 to 12 lb/acre did not injure rice. Rice farmers, in cooperative trials with chemical companies,

TABLE 7.—*Yield of* 'Nato' *and* 'Zenith' *rice as influenced by duration of ducksalad competition, Stuttgart, Ark., 1957–61*[1]

Duration of competition	Rough rice yield (lb/acre)	Yield per acre lost to ducksalad competition		
		Pounds	Percent	Dollar value[2]
0 (check)	5,220	...	...	...
2 weeks	4,910	310	6	16
4 weeks	4,440	780	15	39
8 weeks	3,810	1,410	27	70
All season	4,120	1,100	21	55

[1] Data taken from Smith (*109*).
[2] Rough rice valued at $5/hundredweight.

TABLE 8.—*Rice area treated with propanil, molinate, and phenoxy herbicides and rough rice yields in the United States, 1960–73*[1]

Year	Percentage of rice area treated with[1]—			Rice yield[3] (lb/acre)
	Propanil	Molinate	Phenoxy herbicides[2]	
1960	0	0	70	3,420
1961	1	0	70	3,410
1962	15	0	60	3,730
1963	50	0	50	3,970
1964	60	0	40	4,100
1965	75	0	40	4,260
1966	80	0	40	4,320
1967	85	0	40	4,540
1968	85	2	40	4,420
1969	70	15	40	4,320
1970	70	15	30	4,620
1971	70	15	30	4,720
1972	75	20	30	4,680
1973	80	30	30	4,280

[1] Estimates based on reports by the Cooperative Extension Service in rice-producing States and by herbicide manufacturers.
[2] Includes 2,4-D, 2,4,5-T, silvex, and MCPA.
[3] Yields for 1960–72 were taken from Agricultural Statistics, 1973 (*140*); yields for 1973 were taken from Rice Situation, March 1974 (*141*).

used it in 1961 on about 20,000 acres (*14*). In 1962 propanil was recommended for the first time by the Cooperative Extension Service in Arkansas, Mississippi, and Texas, and farmers treated approximately 250,000 acres with this herbicide. Good to excellent grass control and significant improvements in yields were obtained on more than 90 percent of the fields (*15*). Molinate was first used in commercial rice in 1968, after experiments conducted from 1964 through 1967 indicated that it controlled barnyardgrass and did not injure rice (*86*, *108*, *112*).

Researchers continue to find improved herbicides. Among the promising new ones are bentazon, benthiocarb, bifenox, butachlor, endothall, oxadiazon, KN_3, and NaN_3.

A newly discovered endemic fungus disease has killed northern jointvetch in ricefields (*28*). Aerial sprays of the spores to ricefields in 1972 and 1973 controlled weed plants effectively by 3 to 6 weeks after treatment. Although weed control by the fungus was less rapid than by herbicides such as 2,4,5-T or silvex, activity was fast enough for practical field control. Rice, soybeans, cotton, and other field crops grown in Arkansas were not injured by the fungus.

The development of efficient and economical herbicides and combination methods for full-season control of weeds in rice has had a significant impact on rice production.

Improved yields and quality.—Since 1961 the use of herbicides such as propanil and molinate for the control of weed grasses in rice has steadily increased. Commercial ricegrowers in the United States are now treating most of their rice with herbicides (table 8). Frequently, both herbicides are applied in sequence to the same ricefield. During this period, per-acre yields have increased by approximately 1,200 lb/acre. Better weed control, although not solely responsible, was a vital factor in bringing about increases in yield and improvements in the quality of rice. Also, herbicides, properly used, facilitate good management of other production practices.

Changes in seeding methods and water management.—Ricegrowers in the South have changed from water seeding to dry seeding of rice, because safe and effective herbicides are available to control weed grasses. Water seeding controls weed grasses but fails to prevent infestations of aquatic weeds. Dry seeding, combined with effective herbicides for grass control, reduces problems with weed grasses and aquatic weeds.

In California, a deep flood of 6 to 8 inches is used primarily to control barnyardgrass. A deep flood, however, inhibits growth of young rice seedlings, reduces tillering, and lowers grain yield (*85*). A shallow flood of 1 to 4 inches, combined with the use of effective herbicides, controls weeds and increases yields of rice about 850 lb/acre, compared with deep-flood culture.

Use of improved cultivars.—New high-yielding, lodging-resistant cultivars that are responsive to high levels of nitrogen are practical for commercial production only because effective weed control is possible (*55*). The new short-statured cultivars with upright leaves allow more sunlight to penetrate the crop canopy, and they respond better to nitrogen than taller, leafier cultivars. However, higher light penetration through the crop canopy, combined with high levels of nitrogen, stimulates weed growth.

Cultivars that mature about 115 days after seeding are now used for commercial production (*55*). Frequently two crops are harvested each year from a single early-spring planting of short-season cultivars in the South. Also, short-season cultivars seeded late in the spring extend the spring planting season because they mature before low temperatures damage the crop. These short-season cultivars do not compete well with barnyardgrass and other weeds.

If new, short-strawed, short-season, high-yield cultivars are to be grown efficiently, weeds must be controlled, because they do not compete with weeds as well as older varieties that are taller and leafier or have a longer growing season (*29*). In experiments in Arkansas in 1969, yields obtained when barnyardgrass competed with 'Bluebelle', which matures in 115 days, and with 'Starbonnet', which matures in 140 days, were compared (*117*). All-season competition reduced grain yields of 'Bluebelle' by 64 percent, compared with 40 percent for 'Starbonnet'. Although effective weed control practices are essential for economical production of all new high-yielding cultivars, they are even more important for short-season cultivars, which have less time to grow after the weeds mature than long-season cultivars.

Timely fertilizer management.—New high-yielding rice cultivars adapted for the South are most responsive to nitrogen when part is applied just before seeding or up to 15 days after crop emergence, followed by one or two applications at midseason (*96*). Weeds must be controlled early if the rice is to get maximum benefits from the nitrogen. Where weed grasses are not controlled, nitrogen applied before planting or just after rice emergence often stimulates weed growth and reduces grain yields even more than when no nitrogen is applied at this time (*102*).

Reduction of insect problems.—In Arkansas, rice stink bug (*Oebalus pugnax* Fabricius) populations may be directly related to barnyardgrass infestations (*84*). Fields free of weed grasses may have low populations of stink bugs all season long. Conversely, fields with heavy infestations of barnyardgrass may develop peak stink bug populations about the time rice is most susceptible to damage. Control of barnyardgrass, therefore, reduces stink bug infestations.

Weed infestations affect populations of the rice water weevil (*Lissorhoptrus oryzophilus* Kuschel). A seed treatment of aldrin failed to control rice water weevils in rice heavily infested with barnyardgrass (*126*). Aldrin controlled the insect in rice if barnyardgrass was controlled with herbicides. Therefore, use of a herbicide to control barnyardgrass plus an effective insecticide treatment can reduce rice water weevil infestations more than the use of an insecticide only.

In California, rice water weevil infestations retard vegetative growth of rice during the early growing season and reduce the competitiveness of rice with aquatic weeds. Hence, these weeds grow rapidly and reduce grain yields.

Interdependence of cultural practices and herbicides.—When cultural-mechanical systems fail to control weeds in rice, herbicides are necessary to reduce losses from weeds. Combinations of herbicides in a mixture or in sequential applications are frequently more effective than treatment with only one herbicide.

When weed grasses develop in ricefields because of improper management of cultural-mechanical systems, timely applications of effective rates of propanil or molinate reduce losses from these weeds. Likewise, when aquatic and broadleaf weeds infest ricefields with improperly managed cultural or mechanical control method, timely treatments with phenoxy herbicides can significantly reduce yield and quality losses by these weeds.

By combining control methods into effective systems, most weeds in rice can be controlled. Consequently, high yields of good-quality rice can be produced with a minimum of labor and machinery. Effective weed control also permits the farmer to select seeding methods, varieties, water and fertilizer management practices, insect control programs, and perhaps other rice production practices that favor rice growth and production.

PRINCIPLES OF WEED CONTROL

Weed management systems combine cultural, mechanical, chemical, and biological control programs. Management of cultural and mechanical weed control practices may be used effectively to control specific weeds (table 9).

Preventive methods of weed control are required to avoid weed problems before they begin in ricefields. Preventive methods include use of weed-free crop seed, use of irrigation water free of weed seed or other propagation parts, and use of clean equipment. Conformance to certified seed regulations and use of certified seed are related ways of avoiding weed-seed-contaminated rice seed.

Weeds are disseminated in rice seed and by irrigation water, farm machinery, and birds and animals. Many weeds such as red rice, hemp sesbania, northern jointvetch, dayflower, and mexicanweed are spread almost entirely by rice seed. Even cleaned rice seed may contain these weed seeds because they are difficult to remove.

Red rice, a problem weed in the South, is spread by rice seed contaminated with grains of this weed. Use of rice seed free of red rice seed prevents establishment of red rice on land. Once established, red rice is difficult to control because its seeds shatter easily and can persist in the soil for many years. Since the herbicides presently available for use in rice are not selective enough for control of red rice in the crop, cultural practices that combine crop rotation, fallowing, cultivation, and hand weeding can help to reduce red rice problems.

Seeds of barnyardgrass, northern jointvetch, ducksalad, redstem, and sprangletop are disseminated by irrigation water. When these weeds grow to maturity on canal banks and in ricefields their seeds drop into the water and are scattered through the ricefield.

Machinery carries weed seeds from field to field. Dissemination of weed seeds by machinery may be reduced by cleaning equipment thoroughly after use. Control of weeds in areas where equipment is stored prevents contamination of machinery. Mowing, burning, oiling, grazing, and using soil sterilants help control weeds in these areas.

Weed seeds are carried and disseminated by birds, livestock, and wild animals. Some species of blackbirds feed mainly on weed grasses, such as paspalums (*Paspalum* spp.), barnyardgrass, crabgrass (*Digitaria* spp.), broadleaf signalgrass, and foxtail (*Setaria* spp.). The diet of many blackbird species contains as much as 10 percent barnyardgrass seed (*81*). Livestock that graze ricefield stubble scatter weed seeds from their hoofs and hide and in manure. Livestock that graze weed-infested pastures also contribute to dissemination of weed seeds.

Because weed seeds remain viable in the soil for many years, preventing the establishment of weed plants is essential in a weed control program. In experiments initiated in 1879 in Michigan, freshly gathered seeds of 20 species of weeds were mixed with sand, placed in pint bottles, and buried 18 inches below the ground surface (*7, 93*). After 40 years, seeds of 12 species were viable; after 80 years, seeds of three species—common eveningprimrose (*Oenothera biennis* L.), curly dock (*Rumex crispus* L.), and moth mullein (*Verbascum blattaria* L.)—were viable. Although these weeds are not problems in ricefields, research indicates that seeds of hemp sesbania and northern jointvetch remain viable in the soil for at least 10 years (R. J. Smith, Jr., unpublished data).

Sometimes, viable weed seeds are incapable of germinating immediately after maturity, even when environmental conditions are favorable. This characteristic is called dormancy. Seeds of cocklebur (*Xanthium* spp.), wild oat (*Avena fatua* L.), and redroot pigweed (*Amaranthus retroflexus* L.) exhibit dormancy (*93*). In experiments in Japan barnyardgrass seed lay dormant in the soil for 10 to 48 months after maturity (*4, 5*). Secondary dormancy oc-

TABLE 9.—*Control of common ricefield weeds by selected cultural practices*

Weed	Cultural practice[1]									
	Hand weeding	Clean rice seed[2]	Seedbed preparation	Water seeding	Dry seeding	Timely flooding[3]	Timely draining[3]	Rice stand[4]	Summer fallow	Crop rotation
Algae (green and blue-green)	Poor	Poor	Good	Poor	Good	Poor	Good	Good	Poor	Good
Alligatorweed	Poor	Poor	Good	Poor	Poor	Poor	Poor	Good	Good	Good
Arrowhead	Poor	Good	Good	Poor	Good	Poor	Fair	Good	Good	Good
Barnyardgrass	Poor	Good	Good	Good	Poor	Fair	Poor	Fair	Fair	Fair
Beakrush	Poor	Good	Good	Poor	Fair	Poor	Fair	Good	Good	Good
Broadleaf signalgrass	Poor	Good	Good	Good	Poor	Good	Poor	Fair	Fair	Fair
Bulrush	Poor	Poor	Good	Poor	Good	Poor	Good	Poor	Good	Good
Burhead	Poor	Poor	Good	Poor	Good	Poor	Good	Good	Good	Good
Cattail	Poor	Poor	Good	Poor	Good	Poor	Good	Poor	Good	Good
Common waterplantain	Poor	Poor	Good	Poor	Good	Poor	Good	Good	Good	Good
Dayflower	Poor	Good	Good	Poor	Poor	Fair	Poor	Good	Fair	Fair
Ducksalad	Poor	Poor	Poor	Poor	Fair	Poor	Good	Good	Poor	Poor
Eclipta	Poor	Poor	Poor	Good	Poor	Fair	Poor	Good	Fair	Fair
False pimpernel	Poor	Poor	Poor	Poor	Fair	Poor	Good	Good	Poor	Poor
Fimbristylis	Poor	Poor	Poor	Poor	Good	Poor	Good	Good	Poor	Poor
Gooseweed	Poor	Poor	Good	Poor	Good	Poor	Good	Good	Good	Fair
Hemp sesbania	Good	Good	Good	Fair	Poor	Fair	Poor	Fair	Fair	Fair
Horned pondweed	Poor	Poor	Poor	Poor	Good	Poor	Fair	Good	Fair	Fair
Jointvetch	Good	Good	Good	Fair	Poor	Fair	Poor	Fair	Fair	Fair
Knotgrass	Poor	Poor	Good	Poor	Fair	Poor	Fair	Good	Good	Good
Mexicanweed	Good	Good	Good	Fair	Poor	Fair	Poor	Fair	Fair	Good
Morningglory	Poor	Good	Good	Good	Poor	Good	Poor	Good	Good	Good
Naiad	Poor	Poor	Fair	Poor	Good	Poor	Fair	Good	Fair	Fair
Panicum grasses:										
Annuals	Poor	Poor	Fair	Good	Poor	Fair	Poor	Good	Good	Good
Perennials	Poor	Poor	Good	Poor	Poor	Fair	Poor	Good	Good	Good
Pondweed	Poor	Poor	Good	Poor	Good	Poor	Fair	Good	Good	Good
Red rice	Good	Good	Good	Fair	Poor	Poor	Poor	Fair	Good	Good
Redstem or purple ammannia	Poor	Poor	Poor	Poor	Fair	Poor	Good	Good	Poor	Poor
Smartweed	Poor	Good	Good	Poor	Fair	Poor	Poor	Good	Good	Good
Spikerush:										
Annuals	Poor	Poor	Fair	Poor	Fair	Poor	Good	Good	Good	Good
Perennials	Poor	Poor	Good	Good	Poor	Poor	Poor	Good	Good	Good
Sprangletop	Poor	Good	Fair	Poor	Poor	Poor	Poor	Good	Good	Good
Umbrellaplant:										
Annuals	Poor	Poor	Fair	Poor	Fair	Poor	Good	Good	Good	Good
Perennials	Poor	Poor	Good	Fair	Poor	Fair	Poor	Good	Good	Good
Waterhyssop	Poor	Poor	Poor	Poor	Fair	Poor	Good	Good	Poor	Poor
Waterprimrose	Poor	Good	Good	Poor	Fair	Poor	Fair	Good	Good	Good

[1] Ratings for classes of cultural practice: Good—Practice can be used effectively in commercial rice to prevent or reduce weed infestations. Fair—Practice can be used in commercial rice but usually gives only fair weed control. Poor—Practice cannot be used economically in commercial rice or fails to control the weed.

[2] Seeding weed-free crop seed reduces problems with all weeds. A poor rating indicates that weed seeds do not usually contaminate seed rice. (Weed seeds are not harvested with the crop or can be removed early with commercial cleaning equipment.) A good rating indicates that the weed seeds are difficult to remove from the rice seed and special effort is required to remove the weed seeds.

[3] After crop emergence.

[4] A good rice stand of 12 to 20 plants per square foot helps reduce problems with many weeds.

curred after a period in which the seed germinated. Barnyardgrass seeds were dormant for 10 months immediately after they matured on the plant. Then they went through a period in which they germinated. After submergence in the soil for 4 or 5 months, these seeds went through a period of secondary dormancy in which they failed to germinate. Environmental factors, such as variations in drying and wetting and changes in temperatures, help to break primary and secondary dormancy of barnyardgrass seed.

Experiments therefore indicate that weed seed can remain dormant in soil for long periods and will germinate many years later when environmental and physiological conditions are favorable.

CROP ROTATION

The occurrence of some weed species in rice is often associated with crop rotation. Properly managed rotations combined with the use of herbicides are important for controlling such weeds in rice. Keeping all crops in the rotation free of weeds reduces weeds in the rice crop.

In Louisiana and Texas, a rice-pasture rotation reduces weeds in rice. Rice following poorly drained native pasture frequently becomes heavily infested with perennial weeds such as spikerush and jointed flatsedge. Rice following drained and heavily fertilized improved pasture may become infested with barnyardgrass, but not with perennial weeds such as spikerush, jointed flatsedge, bulrush, or cattails, or with annual broadleaf weeds such as hemp sesbania, mexicanweed, or northern jointvetch. If hemp sesbania, mexicanweed, northern jointvetch, or annual sedges infest the pasture crop, they can be controlled by timely applications of phenoxy herbicides.

In Arkansas, rice-soybean or rice-soybean-oat rotations reduce infestations of barnyardgrass, hemp sesbania, northern jointvetch, spikerush, umbrellaplant, broadleaf signalgrass, beakrush, knotgrass, and red rice. The soybean crop in a rice-soybean-oat rotation can be kept free of weeds by combining cultural practices with the use of preemergence herbicides. The oat crop can be kept free of broadleaf weeds by the use of 2,4-D or MCPA. The land may also be summer-fallowed after oat harvest to control weeds not controlled in the soybeans and oats. Summer fallow is especially effective in controlling barnyardgrass, broadleaf signalgrass, beakrush, knotgrass, and red rice.

Crop rotation coupled with hand pulling of scattered plants is important in controlling red rice. Pasturing, cultivation of soybeans, grain sorghum, or cotton, and summer and fall fallowing after harvesting small-grain crops are some rotation practices that reduce problems of red rice in the rice crop. Herbicides applied preemergence or postemergence to row crops help control red rice in the row crop and reduce infestation in the rice crop.

In California, rotation of rice with fallow or an unirrigated row crop such as safflower controls cattail, bulrush, spikerush and other perennial weeds with large rootstocks. Plowing the ricefield to a depth of 12 inches during the fallow season improves control.

The combination of crop rotation and the use of herbicides is more effective in controlling weeds in rice than either practice used alone. Preemergence and postemergence herbicides applied to the row and pasture crops rotated with rice also reduce weed populations in the rice crop. Likewise, chemical control of grass and broadleaf and sedge weeds in the rice crop reduces weed infestations in the crops rotated with rice.

LAND LEVELING AND LEVEE CONSTRUCTION

Land leveling and proper construction of levees reduce weed infestations. Since level land requires fewer levees, there are fewer sites for weed growth. Barnyardgrass, hemp sesbania, mexicanweed, and northern jointvetch may be more abundant on ridges where water does not cover the land adequately. Weed grasses such as sprangletop and aquatic weeds such as algae, bulrush, ducksalad, gooseweed, redstem, spikerush, umbrellaplant, and waterhyssop grow best in shallow water, 3 inches deep or less, and are most numerous in low areas where surface drainage is inadequate. Thus, land leveling and levee construction to eliminate low and high areas in the ricefield and to maintain 4 to 8 inches of water on the land reduce problems with weeds.

Plastic levees satisfactorily control water in ricefields (*46, 70*) and eliminate barnyardgrass, broadleaf signalgrass, hemp sesbania, morningglory, northern jointvetch, and smartweed, which are problem weeds on soil levees. Covering soil levees with black polyethylene plastic achieves the same purpose.

Herbicides reduce weed problems in ricefields that are not level or where levees are improperly constructed. Silvex, 2,4-D, 2,4,5-T, and MCPA control weeds associated with low areas in ricefields. Likewise, propanil or molinate reduces barnyardgrass infestations, and 2,4-D, 2,4,5-T, and silvex control hemp sesbania, mexicanweed, and jointvetch infestations that are found on ridges in ricefields where 4 to 8 inches of water cannot be maintained. Infestations of barnyardgrass, hemp sesbania, mexicanweed, northern jointvetch, and smartweed on levees are reduced by propanil or phenoxy herbicide treatments.

SEEDBED PREPARATION

Thorough seedbed preparation helps to control most weeds that infest ricefields. The goal is the elimination of weed growth up to the time of planting.

The seedbed may be prepared in many ways—plowing, disking, harrowing, rotary tilling, and combinations of these. The best method to use depends on the soil type and condition, other crops in the rotation, seeding method, climate, and perhaps other considerations. When a rotation includes a spring-harvested crop, the land may be cultivated during the summer and fall by repeated and timely cultivation or disking to rid the field of many weeds. Then the soil may be disked or harrowed again in the spring to prepare a weed-free seedbed for rice.

Repeated cultivations in the spring at 1- to 3-week intervals before seeding rice reduce barnyardgrass and other annual grass infestations. The last cultivation should be shallow—usually not more than 2 or 3 inches deep—to avoid bringing buried weed seeds to the soil surface, where they may germinate. This method does not kill aquatic weeds such as algae, ducksalad, redstem, and annual spikerush or annual species of umbrellaplant because they do not germinate until the soil is flooded. When rice is seeded on heavy clay, a roughly prepared seedbed discourages germination of barnyardgrass, umbrellaplant, spikerush, waterplantain, burhead, and seedling cattail.

In California, thorough plowing, followed by complete drying of soil before seeding rice in water, controls established perennial weeds such as cattail, spikerush, and knotgrass. In the South, spring rains prevent sufficient drying of the soil to kill these weeds.

SEEDING

Rice may be drill-seeded, broadcast-seeded in dry soil and disked or harrowed to cover, or water-seeded. The method of seeding influences subsequent weed growth and weed control. Barnyardgrass, for example, is difficult to control by cultural methods in drill- or dry-broadcast-seeded rice. Seeding in water was therefore developed in California because this method inhibits its germination and growth (*1*).

Water seeding may be used to selectively control barnyardgrass, broadleaf signalgrass, hemp sesbania, northern jointvetch, sprangletop, and red rice. To be effective the water must be held at 4 to 8 inches for 3 to 4 weeks after seeding.

Experiments have shown the relation of water depth, submergence time, and weed control. In pot-culture tests common barnyardgrass seeded on puddled soil was not controlled, but 90 to 100 percent control was obtained by seeding in 2 to 10 inches of water (*57*). Prolonged submergence reduced barnyardgrass infestations and delayed germination and emergence. Some barnyardgrass types, however, germinated in submerged soil. In pot-culture experiments white barnyardgrass, a type of *Echinochloa crus-galli*, germinated when seeded in 10 inches of water, but submergence did delay germination.

In a field experiment where 6 inches of water was held all season, weeds such as barnyardgrass and spikerush were controlled and the rice yield was 5,500 lb/acre (*40*). Where the water was lowered from 6 inches to 2 or 3 inches at 2, 3, and 4 weeks after seeding, the rice yields were 3,500, 2,900, and 3,800 lb/acre, respectively. Where the water was lowered at 2 weeks, barnyardgrass infested the plots. When the water was lowered at 3 or 4 weeks, barnyardgrass was controlled, but spikerush infested the plots and reduced the yield of rice.

Sometimes, however, the water is lowered because it stretches and weakens the rice plant. But weeds such as barnyardgrass, dayflower, hemp sesbania, northern jointvetch, sprangletop, and spikerush germinate when the water is drained. Conversely, water maintained on the ricefield for several weeks after seeding may injure the rice and intensify problems with some aquatic weeds, such as algae, ducksalad, redstem, and waterhyssop.

Dry-seeded culture is more prevalent than water-seeded in the South because a continuous flood during seedling establishment frequently injures the rice. Weeds that develop in dry-seeded rice are more easily controlled with herbicides than are those that develop in a water-seeded culture. Combination treatments of propanil and molinate, applied during the first 3 weeks after crop emergence, control barnyardgrass, broadleaf signalgrass, dayflower, hemp sesbania and northern jointvetch, the prevalent weeds in dry-seeded rice.

WATER MANAGEMENT

Flooding ricefields early in the season to a depth of 4 to 8 inches reduces infestations of barnyardgrass and other weeds, but it may stretch and weaken the rice. Water controls grass plants in the one- to four-leaf stages better than it does larger ones; deep water usually fails to control barnyardgrass that is in the tillering or older stages of growth. High water temperatures, 95° F or above, facilitate control of barnyardgrass, presumably because of the low oxygen content of warm water, but the rice may be injured as well. Rice grown on problem (calcareous, saline, and sodic) soils may be injured severely by deep and prolonged flooding even when water temperatures are optimum (75° to 90° F). Early-season flooding to control weed grasses, therefore, is not always effective and selective.

Timely and thorough draining of the water from the ricefield helps control many aquatic weeds. Experiments in Arkansas showed that blue-green algae, or "scum," are controlled by draining water from the field as soon as green areas of algal growth appear on the soil (*87*). Water is manipulated on and off the field to keep algal growth to a minimum until the rice plants are 12 to 18 inches tall and unaffected by algae. Young ducksalad, redstem, waterhyssop, and other emersed or submersed aquatic weeds are effectively controlled by draining the water and thoroughly drying the field. The rice, however, may be injured if the soil dries and sunbakes. Drying the ricefield to kill aquatic weeds without injury to the crop has a narrow margin of selectivity. Rain may prevent sufficient drying of the soil to control the weeds. Barnyardgrass, broadleaf signalgrass, dayflower, hemp sesbania, northern jointvetch, and other weed grasses and broadleaf weeds may germinate during drainage for the control of aquatic weeds. Weeds may germinate if the water is left off the field for more than 3 or 4 days. Manipulation of the water to control algae, to prevent desiccation of rice, and to forestall germination of barnyardgrass and other weed grasses is difficult to manage in commercial ricefields.

FERTILIZER MANAGEMENT

Weed growth is usually stimulated by applications of phosphate and nitrogen to ricefields, but the ensuing weed competition with the crop can be reduced by selection of times and methods of fertilizer application that are more advantageous to the rice than to the weeds.

There are several ways to apply phosphate fertilizer without excessive stimulation of weed growth. Since seeds of most weeds germinate and grow near the soil surface, phosphate may be placed below the rice seed during drill seeding, where it is less available to the weeds. In fields lightly infested with barnyardgrass, phosphate fertilization may also be delayed until just before the first flooding to take advantage of the inhibition of weed growth by the floodwater. Application of phosphate after flooding stimulates the growth of algae and aquatic weeds, which compete with rice for this nutrient and reduce its availability and benefits to the crop. In fields severely infested with barnyardgrass and other weeds, phosphate is usually applied to another crop in the rotation to avoid the stimulation of weed growth expected after direct application to the rice crop.

Applications of nitrogen can also be made at times when rice benefits more than weeds. In experiments in Arkansas, nitrogen applied before seeding rice or after emergence of weeds stimulated growth of barnyardgrass and aquatic weeds. Nitrogen applications that were delayed until after barnyardgrass headed benefited rice more than earlier applications (table 10). However, nitrogen applications can be managed most efficiently only when weeds are controlled. Nitrogen applied early and at midseason is usually more effective than applications made at midseason only (*47, 96*).

CULTIVATION

Although hand weeding is the main method of weed control in Asian countries (where rice is transplanted into rows), in the United States it is used only to remove scattered infestations in rice grown for seed, and other cultivation methods, except for rotary hoeing, to remove weeds after the rice crop has been seeded are just about nonexistent. In drill-seeded rice, cultivating between rows to remove weeds is difficult, and in dry-broadcast or water-seeded rice, cultivation is impossible.

Rotary hoeing soon after crop emergence controls small weeds in dry-seeded rice. It is the only practical method of cultivation after seed-

TABLE 10.—*Effect of time and rate of nitrogen application on yield of rice heavily infested with barnyardgrass, Stuttgart, Ark., 1957 and 1959*[1]

Stage of barnyardgrass[2]	Nitrogen rate (lb/acre)	Rice yield (lb/acre) 1957	1959	Average
Untreated check	0	2,090	1,900	1,990
Heading	60	2,900	1,780	2,340
Do	120	3,270	2,730	3,000
Do	180	3,470	3,380	3,430
Mature	60	2,390	1,840	2,120
Vegetative and heading[3]	120	2,360	1,370	1,860
Vegetative and mature[3]	120	2,500	1,530	2,010
Heading and mature[3]	120	3,070	2,470	2,770
LSD (5 pct)[4]	...	900	720	810
LSD (1 pct)[4]	...	1,200	950	1,080

[1] Data taken from Smith (*102*).
[2] Vegetative, heading, and mature stages were 3, 8, and 12 weeks after emergence of rice and barnyardgrass, respectively.
[3] 60 lb/acre applied at each stage.
[4] LSD = least significant difference at level given.

TABLE 11.—*Common and chemical names of herbicides, insecticides, and fungicides discussed in this handbook*

Common name or designation	Chemical name
aldrin	1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4-*endo*-*exo*-5,8-dimethanonaphthalene.
bentazon	3-isopropyl-1*H*-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide.
benthiocarb	*S*-[(4-chlorophenyl)methyl] diethylcarbamothioate.
bifenox	methyl 5-(2,4-dichlorophenoxy)-2-nitrobenzoate.
butachlor	*N*-(butoxymethyl)-2-chloro-2′,6′-diethylacetanilide.
carbaryl	1-naphthyl methylcarbamate.
carbofuran	2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate.
copper chelate	copper hydroxide-triethanolamine complex.
copper sulfate	cupric sulfate pentahydrate.
endothall	7-oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid.
fensulfothion	*0,0*-diethyl *0*-[*p*-(methylsulfinyl)phenyl] phosphorothioate.
KN_3	potassium azide.
MCPA	[(4-chloro-*o*-tolyl)oxy]acetic acid.
molinate	*S*-ethyl hexahydro-1*H*-azepine-1-carbothioate.
NaN_3	sodium azide.
oxadiazon	2-*tert*-butyl-4-(2,4-dichloro-5-isopropoxyphenyl)-Δ^2-1,3,4-oxadiazolin-5-one.
parathion	*0,0*-diethyl *0*-(*p*-nitrophenyl) phosphorothioate.
pebulate	*S*-propyl butylethylthiocarbamate.
propanil	3′,4′-dichloropropionanilide.
silvex	2-(2,4,5-trichlorophenoxy)propionic acid.
thiram	bis(dimethylthiocarbamoyl) disulfide.
2,4-D	(2,4-dichlorophenoxy)acetic acid.
2,4,5-T	(2,4,5-trichlorophenoxy)acetic acid.
Panogen	cyano(methylmercuri)guanidine.

TABLE 12.—*Control of common ricefield weeds by selected herbicides*[1]

Weed	Herbicide						
	Propanil	Molinate	2,4-D	MCPA	Silvex	2,4,5-T	Copper
Algae:							
Blue-green	Poor	Poor	Poor	Poor	Poor	Poor	Good
Green	Poor	Poor	Poor	Poor	Poor	Poor	Good
Alligatorweed	Poor	Poor	Fair	Fair	Fair	Fair	Poor
Arrowhead	Poor	Poor	Fair	Fair	Fair	Fair	Poor
Barnyardgrass	Good	Good	Poor	Poor	Poor	Poor	Poor
Beakrush	Fair	Poor	Good	Good	Good	Good	Poor
Broadleaf signalgrass	Good	Fair	Poor	Poor	Poor	Poor	Poor
Bulrush	Poor	Poor	Poor	Fair	Poor	Poor	Poor
Burhead	Poor	Poor	Good	Good	Good	Good	Poor
Cattail	Poor	Poor	Fair	Fair	Fair	Fair	Poor
Common water-plantain	Poor	Poor	Good	Good	Good	Good	Poor
Dayflower	Fair	Fair	Good	Good	Good	Good	Poor
Ducksalad	Fair	Poor	Good	Fair	Fair	Fair	Poor
Eclipta	Good	Good	Good	Good	Good	Good	Poor
False pimpernel	Good	Poor	Good	Good	Good	Good	Poor
Fimbristylis	Good	Poor	Good	Good	Good	Good	Poor
Gooseweed	Poor	Poor	Fair	Fair	Fair	Fair	Poor
Hemp sesbania	Good	Poor	Good	Fair	Good	Good	Poor
Horned pondweed	Poor	Poor	Good	Good	Fair	Fair	Poor
Jointvetch	Good	Poor	Fair	Fair	Good	Good	Poor
Knotgrass	Fair	Poor	Poor	Poor	Poor	Poor	Poor
Mexicanweed	Poor	Poor	Fair	Fair	Good	Good	Poor
Morningglory	Fair	Poor	Good	Good	Good	Good	Poor
Naiad	Poor	Poor	Good	Good	Good	Good	Poor
Panicum grasses:							
Annuals	Good	Good	Poor	Poor	Poor	Poor	Poor
Perennials	Fair	Poor	Poor	Poor	Poor	Poor	Poor
Pondweed	Poor	Poor	Fair	Fair	Fair	Fair	Poor
Red rice	Poor	Fair	Poor	Poor	Poor	Poor	Poor
Redstem or purple ammannia	Fair	Poor	Good	Good	Good	Good	Poor
Smartweed	Fair	Poor	Fair	Fair	Fair	Fair	Poor
Spikerush:							
Annuals	Good	Good	Good	Good	Good	Good	Poor
Perennials	Fair	Poor	Fair	Fair	Fair	Fair	Poor
Sprangletop:							
Bearded	Fair	Poor	Poor	Poor	Poor	Poor	Poor
Tighthead	Good	Poor	Poor	Poor	Poor	Poor	Poor
Umbrellaplant:							
Annuals	Fair	Fair	Good	Good	Good	Good	Poor
Perennials	Fair	Fair	Fair	Fair	Fair	Fair	Poor
Waterhyssop	Good	Poor	Good	Good	Good	Good	Poor
Waterprimrose	Poor	Poor	Fair	Fair	Fair	Fair	Poor

[1] Susceptibility of weeds based on observations made in greenhouse and field experiments and in ricefields from general applications. Good—1 application at susceptible stage of growth and at normal rates kills 70 to 100 pct of the weeds with little or no injury to rice. Fair—1 application at normal rates at susceptible growth stages kills only 40 to 60 pct of the weeds with little or no injury to rice. Poor—Weeds not controlled with normal rates applied at susceptible growth stages. Normal rates for propanil, 3 to 6 lb/acre; for molinate, 2 to 3 lb/acre; for 2,4-D, MCPA, silvex, and 2,4,5-T, 0.5 to 1.5 lb/acre; for copper sulfate, 0.5 part per million by weight of copper.

ing, but it is seldom used because it is only effective when the soil is neither too dry nor too wet.

HERBICIDES

Some herbicides are registered for use in rice and others that have been researched show promise for control of weeds in rice. Herbicides and other pesticides and chemicals discussed in this handbook are presented in table 11.

Weeds, which vary in their susceptibility to herbicides, may be controlled by proper herbicide management. Table 12 gives relative susceptibility of problem ricefield weeds to various registered herbicides.

General Information About Herbicide Use

Drift

Field crops such as cotton and soybeans and certain horticultural, fruit, and ornamental plants may be injured by drift from herbicide spray. Size and density of spray droplets, herbicide formulation, vapor pressure of spray solution, wind velocity and direction, height of spray nozzle above the treated surface, air temperature and relative humidity, and possibly other factors influence drift of herbicides. The effect of droplet size on drift of sprays is shown in table 13.

Many different distribution systems are used for spraying herbicides by aircraft. They range from the most common boom-nozzle system to various spinning brushes, disks, and screens.

TABLE 13.—*Drift of spray as influenced by droplet diameter*[1]

Drop diameter (μm)	Particle type	Distance particles carried
400	Coarse aircraft sprays	8 ft
150	Medium aircraft sprays	22 ft
100	Fine aircraft sprays	48 ft
50	Very fine aircraft sprays	178 ft
20	Fine sprays and dusts	1,100 ft
10	Usual dusts and aerosols	4,500 ft
2	Fine aerosols	21 mi

[1] Water solutions of herbicides sprayed from 10 ft above ground in a wind of 3 mi/h. Adapted from Brooks (*16*) and Akesson and Yates (*3*).

Chemical formulations vary from water-soluble materials to thick, viscous liquids. Regardless of the distribution system or the chemical formulation used, droplets vary from aerosols to coarse. However, the distribution system and chemical formulation used may affect the amount of the spray found in each droplet-size class. For example, experiments in California indicated that although aerial applications of viscous invert (water-in-oil) emulsions contained fine droplets which drifted, as did oil-in-water emulsion sprays, they contained more large particles that were deposited in the application swath.[2] Therefore, the amount of spray that drifted from the target area was less with invert-emulsion than with normal-emulsion sprays.

Atomization of aerial spray is affected by the type of nozzle used. Hollow-core nozzles produce fine sprays, but flood or jet nozzles produce coarse sprays. The operating pressure of the system and discharge angle of the nozzle in relation to the airstream of the airplane also affect droplet size. Atomization increases as the operating pressure increases; it also increases as the nozzle discharge outlet is angled into the airstream. Physical properties of the spray solution, such as density, surface tension, and viscosity, also affect atomization.

States regulate the spraying of herbicides by ground and aerial equipment. These regulations, which deal with equipment, herbicide formulation, wind velocity, records, responsibility, and liability, should be consulted before spraying ricefields with herbicides.

Phenoxy herbicides.—Cotton and soybeans are highly susceptible to phenoxy herbicides. Cotton is injured more by 2,4-D than by silvex, 2,4,5-T, or MCPA (table 14). The growth stage at treatment, environment, soil, formulation of herbicide, and possibly other factors affect the response of cotton to phenoxy herbicides. Silvex and 2,4,5-T injure soybeans more than 2,4-D. Soybeans treated in the vegetative stage are injured more than those treated in the bloom

[2] Akesson, W. B., and Yates, W. E. Application aspects of viscous emulsions as an agricultural spray formulation. Paper presented at the American Society of Agricultural Engineers meeting, Dec. 12–15, 1961, Chicago, Ill.

stage (table 15). Cotton and soybeans are usually injured less by amine salt than by ester formulations.

Spray-drift injury of susceptible crops or plants by amine salts and low-volatility esters usually occurs during spraying, not afterward. However, at temperatures above 95° F, even low-volatility esters may vaporize after spraying, then drift and injure nearby susceptible crops (*27*).

Propanil.—Drift from propanil spray may injure susceptible crops. Cotton plants 2 to 4 inches tall are injured more than those 10 to 22 inches tall (table 16). Applications at rates of 0.5, 1, and 2 lb/acre at both stages of growth reduced yields significantly. At rates of 0.25 lb/acre or more, propanil delayed maturity of cotton. When cotton plants 10 to 22 inches tall were treated with 2 lb/acre only 3 percent of the seed cotton was harvested the first picking compared with 53 percent for untreated cotton. Propanil at 1 or 2 lb/acre applied to soybeans 2 to 5 and 10 to 25 inches tall reduced yields, but rates of 0.5 lb/acre or less did not (table 17). Propanil at 2 lb/acre reduced soybean yields most when applied to 2- to 5-inch-tall plants. Cotton was more susceptible than soybeans to propanil, but yields of both crops were reduced when propanil reduced stands.

Propanil injury was manifested on both crops as brown and yellow mottling on leaves, necrosis along leaf margins, reduction in height,

TABLE 14.—*Yield reduction of cotton after treatment with phenoxy herbicides*

[Percent]

Location and herbicide	Cotton stage at treatment			
	Vegetative	Square	Flower	Boll
California:[1]				
2,4-D	...	94	78	0
Silvex	...	52	55	11
2,4,5-T	...	61	46	3
Louisiana:[2]				
2,4-D	43	32	...	9
Silvex	14	11	...	9
2,4,5-T	16	14	...	9
Mississippi:[3]				
2,4-D	62	66	34	16
2,4,5-T	34	20	16	10
MCPA	24	21	8	10
Texas:[4]				
2,4-D	84	70	54	15
Silvex	51	28	18	10
2,4,5-T	69	44	42	13
MCPA	78	65	17	1

[1] Average yield reduction from plots treated with low-volatility esters applied at 0.01 lb/acre in 1954 and 1955 (*77*). Untreated checks yielded an average of 2,490 lb/acre of seed cotton.

[2] Average yield reductions from plots treated with amine salts applied at 0.0001 to 0.1 lb/acre in 1955, 1956, and 1957 (*91*). Untreated checks yielded an average of 2,200 lb/acre of seed cotton.

[3] Average yield reductions from plots treated with amine salts applied at 0.01 and 0.1 lb/acre in 1951, 1952, and 1953 (*44*). Untreated checks yielded an average of 1,810 lb/acre of seed cotton.

[4] Average yield reductions from plots treated with low-volatility esters applied at 0.05 and 0.1 lb/acre at 2, 3, or 4 locations in 1954 (*8*). Untreated checks yielded an average of 330 lb/acre of lint cotton.

TABLE 15.—*Yield reduction of* 'Lee' *soybeans after treatment with phenoxy herbicides, Stuttgart, Ark., 1958 and 1959*[1]

[Percent]

Herbicide[2] and rate (lb/acre)	Soybean stage at treatment[3]		Average
	Vegetative	Bloom	
2,4-D:			
0.01	5	10	8
.05	19	8	14
.10	28	7	18
.25	50	10	30
Average	26	9	18
2,4,5-T:			
0.01	14	4	9
.05	30	26	28
.10	45	41	43
.25	74	60	67
Average	40	33	37
Silvex:			
0.01	10	8	9
.05	28	26	28
.10	48	34	41
.25	90	66	78
Average	44	34	39

[1] Untreated weed-free checks yielded an average of 44 bu/acre of soybeans. Data taken from Smith (*106*).

[2] Amine salts of 2,4-D and 2,4,5-T used; low-volatility ester of silvex used.

[3] Plants in the vegetative stages were 6 to 12 inches tall; those in the early bloom stage were 30 to 36 inches tall.

and death of plants. Plants that were not killed grew new leaves, recovered vegetatively, and produced nearly normal yields, but maturity was often delayed. Older plants recovered more quickly and completely than younger ones.

Molinate.—Drift of molinate from spray or granular application may damage susceptible crops. Soybeans, injured vegetatively by direct applications of granular molinate at 3 to 6 lb/acre, were not reduced in yield (R. J. Smith, Jr., unpublished). Treated plants exhibited leaf crinkling, chlorosis, and necrosis.

Residues

Federal laws provide for establishing maximum levels, called tolerances, of residual herbicides on and in raw agricultural products. Rough and milled rice are classed as raw agricultural products. Tolerances of 2 parts per million in rice grain and 75 parts per million in straw have been established for propanil by the Federal Environmental Protection Agency. A tolerance of 0.1 part per million in rice grain and straw has been established for molinate. Tolerances for 2,4-D, 2,4,5-T, MCPA, and silvex have not been established, but the use of these herbicides for weed control in rice is permissible until tolerances are set.

The label directions on pesticide containers are subject to clearance under the Federal Insecticide, Fungicide, and Rodenticide Act as amended. Clearance is withheld if, on the basis of experimental evidence, the use proposed may result in residues exceeding established tolerances. Container labels, therefore, furnish a reliable guide for using pesticides in a way that will avoid excessive residues.

Some herbicides persist at toxic levels in soil; others are degraded, altered, or inactivated by micro-organisms or by absorption to soil colloids, leaching, volatilization, photodecomposition, and perhaps other ways (*67*). Factors that affect persistence include soil type, moisture and organic matter in soil, rainfall, temperature, herbicide type, cropping system, and cultivation procedures. Applied to ricefields at normal rates, the phenoxy herbicides 2,4-D, MCPA, and 2,4,5-T persist in soil for 1, 3, and 5 months, respectively (*64*); molinate may persist for about 1 month; and only small amounts (0.2 part per million or less by weight) of propanil are found 2 to 4 weeks after treatment (*65*). Silvex is more persistent than 2,4-D but less persistent than 2,4,5-T. Although propanil may convert to 3,3′,4,4′-tetrachloroazobenzene (TCAB), only small quantities (less than 0.2 part per million by weight) are found (*65*). Herbicides used for control of weeds in rice are sufficiently short-lived that their residues are not injurious to other crops planted after harvesting rice.

Storage

Some agricultural chemicals may be danger-

TABLE 16.—*Effect of time and rate of propanil applications on yield of seed cotton, Rohwer, Ark., 1961–63*[1]

Propanil (lb/acre)	Yield of seed cotton (lb/acre) 1961	1962	1963	Average	Reduction in yield (pct)[2]
COTTON 2 TO 4 INCHES TALL WHEN SPRAYED					
0.01	1,520	2,360	2,890	2,260	2
.05	1,980	2,360	2,400	2,250	3
.1	1,260	2,120	2,540	1,970	15
.25	1,430	1,920	2,760	2,040	12
.5	750	1,760	2,270	1,590	31
1.0	570	1,510	2,100	1,390	40
2.0	120	940	930	660	72
Average	...	...	...	1,740	25
COTTON 10 TO 22 INCHES TALL WHEN SPRAYED					
0.01	1,390	2,410	2,650	2,150	7
.05	1,610	2,210	2,550	2,120	8
.1	1,770	2,290	2,680	2,250	3
.25	1,620	2,080	2,580	2,090	10
.5	870	2,160	2,430	1,820	21
1.0	880	2,160	2,210	1,750	24
2.0	570	1,710	2,060	1,450	37
Average	...	...	...	1,950	16
UNTREATED CHECK					
0	2,020	2,330	2,580	2,310	0
LSD (5 pct)[3]	500	280	480	420	18

[1] Weeds controlled in all plots. Data taken from Smith (*108*).

[2] Yield expressed as percentage reduction compared with yield of the untreated check.

[3] LSD (least significant difference) applies to stage by rate averages ("Average" column), but not to stage averages.

ous in storage if formulated with solvents having low flash points (140° F or less). The herbicides used for weed control in rice have relatively high flash points; therefore, spontaneous combustion is not likely to occur during storage or use of these chemicals.

Proper storage is essential to prevent the deterioration of herbicides and their containers. Dust and wettable powders stored in a dry place do not deteriorate rapidly, but if they get wet, they may cake and the packages may deteriorate. Water-soluble solids may cake when wet and when subjected to great changes in temperature. If packages are left open, hygroscopic chemicals become wet by absorbing water from moist air. It is essential, therefore, to store containers tightly sealed in cool, dry areas.

Liquid formulations can be stored on pallets or duckboards to prevent water condensation and rusting of metal containers. Tightly closed containers reduce herbicide deterioration. Small amounts of water introduced into emulsifiable concentrates or oil solutions may cause jelling or corrosion of the container.

Liquid formulations of phenoxy herbicides, propanil, and molinate may crystallize or precipitate at temperatures below 30° F. The crystals can usually be redissolved by rolling or shaking the container after the liquid has been warmed to 40° F or slightly higher. If the crystals dissolve, the herbicide is usable; if they do not, the herbicide cannot be applied properly.

Liquid herbicides may become unusable if stored at temperatures above 95° F. Herbicides stored in drums expand upon warming, and the increased internal pressure may cause the containers to leak. High temperatures may also reduce the effectiveness of emulsifiers and hasten the corrosion of containers. In direct sunlight in hot weather, herbicide drums become excessively hot. Therefore, storage of herbicides in the shade or in well-ventilated buildings or sheds during hot weather reduces the chances of deterioration.

TABLE 17.—*Effect of time and rate of propanil applications on yield of soybeans, Stuttgart, Ark., 1961–63*[1]

Propanil (lb/acre)	Yield of soybeans (bu/acre)				Reduction in yield (pct)[2]
	1961	1962	1963	Average	
SOYBEANS 2 TO 5 INCHES TALL WHEN SPRAYED					
0.01	38	27	35	33	0
.05	37	26	37	33	0
.1	36	26	35	32	3
.25	34	26	31	30	9
.5	30	25	34	30	9
1.0	28	21	36	28	15
2.0	25	18	24	22	33
Average	...	...	...	30	9
SOYBEANS 10 TO 25 INCHES TALL WHEN SPRAYED					
0.01	36	26	34	32	3
.05	32	27	33	31	6
.1	38	26	34	33	0
.25	38	24	33	32	3
.5	34	24	33	30	9
1.0	32	23	29	28	15
2.0	34	23	25	27	18
Average	...	...	...	30	9
UNTREATED CHECK					
0	37	27	34	33	0
LSD (5 pct)[3]	3	4	4	4	12

[1] Weeds controlled in all plots. Data taken from Smith (*108*).

[2] Yield expressed as percentage reduction compared with yield of untreated check.

[3] LSD (least significant difference) applies to stage by rate averages ("Average" column), but not to stage averages.

Handling

Although the herbicides used in rice are comparatively low in oral and dermal toxicity to humans and animals, contact should be avoided. Ingestion of even small quantities of some herbicide concentrates or spray solutions can cause severe acute or chronic illness or even death. They may also be irritating to the skin and eyes. Washing the skin or eyes thoroughly with clean water immediately after accidental contact can prevent severe injury. If repeated and prolonged exposure is likely, goggles and protective clothing should be worn. Poison control centers located throughout the United States disperse information on treatments to administer if pesticides are ingested or contacted.

Fish and wildlife may be injured if ponds, lakes, or streams are contaminated with herbicides. Feed or food stored near herbicides may become contaminated. Fumes from volatile herbicide containers are likely to offset the viability of seed, including rice seed, stored nearby.

Cleaning spray equipment

Phenoxy herbicides are difficult to remove from spray equipment. Since even traces of these chemicals may severely injure cotton, tomatoes, and other sensitive plants, equipment used to spray phenoxy herbicides should never be used to apply other chemicals to these plants. After thorough cleaning, a sprayer used for phenoxy herbicides can be used to apply fungicides, insecticides, and other herbicides to moderately sensitive crops such as soybeans, clover, and lespedeza. Thoroughly cleaned sprayers previously used for applications of propanil and molinate can be used to apply other pesticides to most plants, including cotton, soybeans, clover, lespedeza, small grains, and vegetable crops.

Thorough cleaning of a sprayer with warm water and detergent removes most of the herbicide in the sprayer. Further cleaning is usually necessary and may be accomplished with a solution of 1 part household ammonia in 100 parts of water. Cleaning is enhanced when this solution remains in the tank, hose, and boom for 12 to 24 hours before rinsing the equipment with clean water.

Finely ground activated charcoal is one of the best agents for cleaning herbicides from spray equipment; it is faster and more effective than household ammonia. Phenoxy herbicides can be removed by rinsing the sprayer for about 2 minutes with a 1-percent suspension of activated charcoal (for example, 1 pound of powdered activated charcoal in 12 gallons of water), followed by rinsing with clean water. The addition of a detergent to the water aids in wetting and suspending the activated charcoal so that it can be rinsed easily from the tank. Residues of activated charcoal in the tank could reduce the activity of the next chemical to be sprayed.

To be sure the sprayer has been adequately cleaned, add water to the tank and spray it on seedlings of a sensitive plant, such as bean, tomato, or morningglory. If the seedlings are not injured after 1 or 2 days, the equipment is probably clean enough for use on moderately sensitive plants.

Propanil

Propanil, which is only slightly soluble (500 p/m) in water, but highly soluble (about 25 percent) in most common organic solvents, is formulated with organic solvents and emulsifiers and is slightly volatile at high temperatures (95° to 100° F). The acute oral LD_{50} of technical propanil for rats is low, 1,384 mg/kg.

Mode of selectivity

Propanil applied to emerged rice and weeds selectively kills barnyardgrass and many other grass, aquatic, broadleaf, and sedge weeds, while rice is only slightly injured (table 12). The basis of this selectivity is biochemical. Experiments with a radioactive isotope of propanil indicate that both rice and barnyardgrass absorb and translocate propanil rapidly and equally (*150*). An enzyme, aryl acylamidase, in the leaves of rice plants rapidly detoxifies propanil by oxidative metabolism and hydrolysis to 3,4-dichloroaniline (DCA) and propionic acid (*38*). Young rice leaves contain approximately 60 times as much aryl acylamidase as young barnyardgrass leaves. Roots of rice and barnyardgrass contain the same low concentrations of the enzyme.

In propanil-treated rice, the DCA hydrolysis product becomes tightly bound in carbohydrate and lignin constituents of the cell walls of the rice plant, from which it can be released only by extreme caustic treatment (*130, 151*). DCA was found at higher concentrations in the straw than in the grain. The propionic acid, formed by the hydrolysis of propanil, is further metabolized to carbon dioxide and water by beta-oxidation (*129*).

Scientists in Japan found a rice mutant that is susceptible to propanil (*75*). Research indicated that this susceptible rice hydrolyzes propanil at a much slower rate than the tolerant rice. Apparently, the susceptible rice contained a very low concentration of the propanil-hydrolyzing enzyme.

TABLE 18.—*Effect of propanil application rate on barnyardgrass control and rice yields, Stuttgart, Rohwer, and Keiser, Ark., 1960–64*

[Propanil applied to 1- to 4-leaf grass, 1 to 3 inches tall, and 1- or 2-leaf rice, 3 to 4 inches tall]

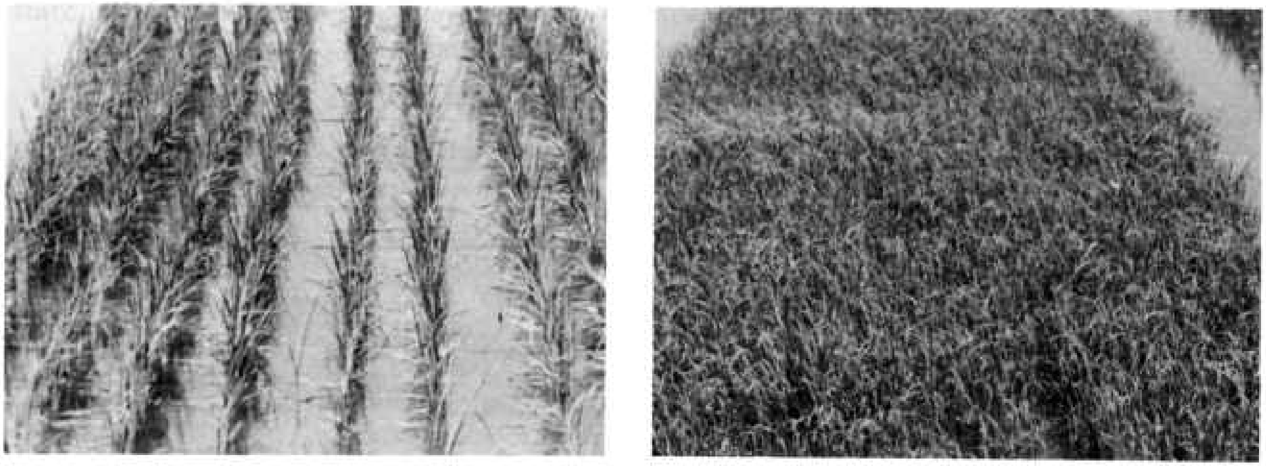
Year and location	Barnyardgrass control[1] (pct)								Rough rice yield (lb/acre)								
	Propanil rate (lb/acre)							LSD	Propanil rate (lb/ acre)								LSD
	2	3	4	5	7	9	12	(5 pct)[2]	0	2	3	4	5	7	9	12	(5 pct)[2]
1960																	
Stuttgart	..	80	..	84	88	..	..	8	2,640	.....	4,640	.....	4,700	4,630	.....	.....	330
1961																	
Stuttgart	..	57	..	70	77	73	..	15	2,340	.....	3,520	.....	3,670	4,050	3,630	.....	550
Rohwer	70	85	..	85	88	83	87	([3])	2,460	3,110	3,320	.....	3,380	3,400	3,410	3,730	([4])
Keiser	70	78	..	86	91	96	99	10	3,490	3,840	3,700	.....	4,000	3,860	3,930	3,590	([4])
1962																	
Stuttgart	..	65	..	85	90	89	..	12	2,590	.....	3,930	.....	4,610	4,850	4,750	.....	650
Do	72	80	85	...	..	..	..	([5])	2,960	4,690	5,020	5,540	.....	.....	.....	.....	980
Rohwer	..	99	..	100	..	..	..	([3])	2,860	.....	4,180	.....	4,100	.....	.....	.....	420
Keiser	..	70	..	85	..	..	..	([3])	1,260	.....	2,950	.....	3,450	.....	.....	.....	390
1963																	
Stuttgart	35	85	78	...	..	..	..	23	3,150	4,020	5,180	4,620	.....	.....	.....	.....	670
Keiser	..	96	..	98	..	..	..	([5])	2,770	.....	3,870	.....	3,700	.....	.....	.....	450
1964																	
Stuttgart	90	100	98	...	..	..	..	([5])	3,460	6,060	6,450	6,400	.....	.....	.....	.....	740
Rohwer	..	85	..	97	..	..	..	([5])	2,900	.....	5,570	.....	5,770	.....	.....	.....	420
Average	67	82	87	88	87	85	93	([5])	2,740	4,340	4,360	5,520	4,150	4,160	3,930	3,660	([5])

[1] Measurements made at midseason after grass matured.
[2] LSD = least significant difference at level given.
[3] No significant differences at the 5-pct level.
[4] Yield of untreated rice was significantly less than that of treated rice at the 5-pct level, but yields of plots treated at 2 to 12 lb/acre were not significantly different at the 5-pct level.
[5] Not determined.

TABLE 19.—*Effect of time and rate of propanil application on barnyardgrass control and rice yield, Stuttgart, Ark., 1960*

Grass stage at treatment	Barnyardgrass control (pct)				Rough rice yield (lb/acre)			
	Propanil rate (lb/acre)			Average	Propanil rate (lb/acre)			Average[1]
	3	5	7		3	5	7	
After seeding	17	18	15	17	2,320	2,660	2,930	2,640
1 leaf, ½ inch[2]	58	52	64	58	4,100	3,720	4,100	3,970
2 or 3 leaves, 2 inches	80	84	88	84	4,640	4,700	4,630	4,660
LSD (5 pct)[3]	...	...	...	8	...	...	...	330
LSD (1 pct)[3]	...	...	...	11	...	...	...	440

[1] The hoed and unhoed checks yielded 4,720 and 2,640 lb/acre, respectively.
[2] Barnyardgrass reinfested plots after herbicide treatment.
[3] LSD = least significant difference at level given.



PN-4935 PN-4936

FIGURE 1.—Control of barnyardgrass in rice with propanil. *Left*, plot sprayed with propanil at 4 lb/acre when barnyardgrass had two or three leaves. *Right*, unsprayed plot.

PN-4937

FIGURE 2.—Growth stages of barnyardgrass. *Left to right*, plants in one-, two-, three-, four-, and five-leaf and tillering stages.

Time and rate of application

Propanil applied at 3 to 5 lb/acre controls barnyardgrass 1 to 3 inches tall, in the one- to four-leaf stage of growth, with little or no injury to rice (tables 18 and 19, figs. 1 and 2). These rates are considered optimum for weed control in rice. It is usually ineffective as a preemergence application or when applied to barnyardgrass in the tillering stage of growth or later (table 20).

Ducksalad 1 inch tall or less is controlled by propanil, but plants 2 to 6 inches tall are usually resistant (table 21). Likewise, young gooseweed, northern jointvetch, and purple ammannia plants 1 to 3 inches tall are controlled, but older ones, 12 to 24 inches tall, are resistant. Propanil controls blunt spikerush 3 inches tall, dwarf spikerush 1 inch tall, hemp sesbania 2 to 48 inches tall, tighthead sprangletop 2 inches tall, waterhyssop 4 inches tall, and yellow foxtail [*Setaria glauca* (L.) Beauv.] 4 inches tall. It does not control dayflower or morningglory plants that are 2 to 4 inches tall or taller.

Temporary chlorosis and tipburn on rice leaves may occur soon after treatment with propanil at rates of 3 to 5 lb/acre, but permanent injury usually does not occur even at rates as high as 12 lb/acre. Such temporary injury is caused mainly by formulation solvents. Injury of rice is more pronounced and persists longer when temperatures are either extremely low (daily lows below 50° F) or extremely high (daily highs above 95° F) at the time of treatment. Even when injury seems severe, rice plants usually recover within 2 weeks after treatment, and new leaves that emerge after treatment show no injury symptoms.

Propanil controls rapidly growing weeds effectively, but frequently fails to control weeds growing slowly under conditions of low moisture or low temperatures. It controls barnyardgrass seedlings growing rapidly in moist soil better than slow-growing ones in dry soil. In a 1961 field experiment propanil became decreasingly effective against barnyardgrass as the weed plants increased in size (table 20). In 1962 the effectiveness of propanil again decreased as the grass plants increased in size from ½ to 2 inches to 6 to 13 inches tall. But applications to grass 10 to 36 inches tall (tillering-to-jointing and jointing-to-heading stages of growth) controlled grass better than treatment of plants 6 to 13 inches tall (tillering stage). The increased control of 10- to 36-inch-tall grass was caused by an application of nitrogen 1 to 2 weeks before treatment, which stimulated growth of the grass. Propanil controlled the larger fast-growing grass better than it controlled the smaller slow-growing grass. The results of this experiment indicate that the growth rate of weeds can affect the efficacy of propanil.

Propanil kills barnyardgrass plants that have emerged, but it fails to control those that emerge after treatment (table 19). Weed grasses and aquatic, broadleaf, and sedge weeds that germinate after treatment become troublesome and reduce yields. Usually all weed grasses have emerged by the time the oldest grass reaches the four-leaf stage, but sometimes they emerge after treatment if the floodwater is not applied in time or if the flood has to be drained.

Propanil is usually applied at the most susceptible growth stage of the grass. When barn-

TABLE 20.—*Effect of time of propanil application on barnyardgrass control and rice yields, Stuttgart, Ark., 1961 and 1962*

[Values are averages from plots treated with 3, 5, 7, and 9 lb/acre]

Grass stage at treatment	1961	1962	Average
	Grass control (pct)[1]		
½ to 2 inches or 1 to 4 leaves	69	100	74
½ to 7 inches or 2 leaves to tillering	60	82	71
2 to 8 inches or tillering	48	50	49
6 to 13 inches or tillering	17	22	20
10 to 20 inches or tillering to jointing	0	42	21
15 to 36 inches or jointing to heading	10	46	28
LSD (5 pct)[2]	11	16	14
LSD (1 pct)[2]	16	23	20
	Rice yield (lb/acre)[3]		
½ to 2 inches or 1 to 4 leaves	3,720	4,680	4,200
½ to 7 inches or 2 leaves to tillering	3,570	4,530	4,050
2 to 8 inches or tillering	3,440	3,950	3,700
6 to 13 inches or tillering	2,700	3,070	2,890
10 to 20 inches or tillering to jointing	2,310	3,510	2,910
15 to 36 inches or jointing to heading	2,530	3,380	2,950
LSD (5 pct)[2]	440	890	660
LSD (1 pct)[2]	630	1,060	840

[1] In 1961 nitrogen fertilizer was applied after the last spraying; in 1962 it was applied 7 and 14 days before the tillering-to-jointing and jointing-to-heading treatments, respectively. Measurements were made at midseason after grass matured.

[2] LSD = least significant difference at level given.

[3] There was no grass-free check plot, but the untreated check plots yielded 2,340 and 2,010 lb/acre, respectively, in 1961 and 1962.

TABLE 21.—*Control of weeds in various stages with propanil, Stuttgart, Rohwer, and Keiser, Ark., 1960–64*

Weed	Weed height (inches)	Year	Percentage of weed control with propanil applied at (lb/acre)—						
			0.5	1	2	3	4	5	8
Ducksalad	1	1962	..	..	...	70	...	...	..
	2	1962	..	..	...	40	...	...	..
	6	1960	20	0	20	...	10	...	..
	6	1961	..	..	10	...	20	...	..
	6	1962	..	..	40	50	...	...	..
Northern jointvetch	3	1963	..	..	...	80	...	...	..
	24	1960	..	0	20	...	10	...	50
	24	1961	20	40	30	...	80	...	..
	24	1962	..	..	20	20	...	...	..
Purple ammannia	1	1962	..	..	...	90	...	...	..
	12	1960	..	0	0	...	20	...	40
Gooseweed	3	1962	..	..	...	90	...	...	..
	24	1960	..	10	50	...	40	...	80
Waterhyssop	4	1962	..	..	70	80	...	...	..
Hemp sesbania	2	1961	..	..	70	80	...	80	90
	2	1962	..	..	...	90	...	...	..
	2	1963	..	..	...	90	...	...	..
	2	1964	..	..	...	100	...	100	..
	24	1961	50	40	90	...	100	...	..
	36	1962	..	..	90	90	...	...	..
	48	1960	..	20	100	...	100	...	80
Tighthead sprangletop.	2	1962	..	..	...	90	...	...	..
	2	1963	..	..	...	100	...	100	..
	2	1964	..	..	...	90	...	100	..
Blunt spikerush	3	1962	..	..	...	90	...	...	..
Dwarf spikerush	1	1962	..	..	...	90	...	...	..
	1	1963	..	..	...	90	90	...	..
Yellow foxtail	4	1963	..	..	...	100	...	100	..
Tall morningglory	2	1963	..	..	...	30	...	...	..
	4	1962	..	..	...	30	...	...	..

yardgrass has reached the one- to four-leaf stage of growth, rice usually has one or two leaves, but it may be smaller or larger. A satisfactory stand of rice before propanil treatment is desirable. The propanil treatment would be wasted on a poor stand of rice that had to be replanted after treatment.

Water management

Irrigating dry ricefields 2 to 5 days before propanil treatment increases weed control. In an experiment at Stuttgart, Ark., barnyardgrass grew slowly and was not controlled by propanil when rice was seeded in soil sufficiently moist for germination of rice and grass, but which did not receive any rain during the 11-day period from planting to spraying. Irrigation water applied 3 days before spraying stimulated growth of barnyardgrass and increased control. In this experiment, propanil controlled 90 percent of the barnyardgrass that grew in moist soil, but it controlled only 70 percent of the grass that grew in dry soil.

Propanil does not kill weeds covered with water at the time of treatment because it cannot contact the leaves of the weeds. Flooding rice 3 to 4 inches deep 1 to 5 days after treatment prevents the germination of more barnyardgrass plants. In experiments at Stuttgart, Ark., propanil controlled 80 percent of the grass in plots flooded 5 days after spraying, but only 10 percent in plots flooded 22 days after treatment. Grass plants that emerged during the 17-day delay of flooding reduced rice grain yields.

Some commercial ricefields are so large that timely flooding after a propanil treatment may be difficult. If a large ricefield is sprayed all at once, weed grasses may germinate after the treatment in some areas where flooding is delayed. Separate treatment of portions of large fields to permit timely flooding with the available water supply prevents weed grasses from reinfesting sprayed fields.

Method of application

Propanil may be applied by ground or aerial spray equipment. Boom-nozzle sprayers are commonly used for ground treatments. Boom-nozzle, venturi, or rotary-atomizer sprayers, when properly adjusted, are satisfactory for aircraft spraying. Fixed-wing and helicopter aircraft can be used to apply propanil. Aircraft spraying is usually better than by ground rigs because levees do not reduce spraying efficiency, and fields too wet to support ground equipment can be sprayed rapidly and at the correct time. Propanil sprays applied in medium-fine droplets (200 to 300 micrometers in diameter while in the air) cover weeds sufficiently for effective control and are less likely to drift than finer droplets.

The spray pattern of aircraft and tractor sprayers affects the efficacy of propanil treatments. Propanil is most effective when the spray covers the weeds well. When fixed-wing aircraft sprayers are properly adjusted, a swath width of 30 to 40 feet (equal to or slightly less than the wingspan of the aircraft) usually gives good spray coverage. When tractor or helicopter sprayers are properly adjusted, the length of the spray boom governs the swath width. Operation of aircraft 8 to 10 feet above the ground usually permits satisfactory spray coverage and minimizes spray drift.

Spray volume

Adequate coverage of leaves with propanil spray is required for effective weed control. Normally propanil applied with water carrier at 15 to 20 gal/acre controls weeds satisfactorily when tractor sprayers are used, and volumes of 10 to 15 gal/acre are sufficient when spraying by aircraft. Propanil sprays applied in volumes below 15 gal/acre with tractor sprayers or below 10 gal/acre with aircraft sprayers frequently control weeds less effectively and are more susceptible to drift than applications at higher spray volumes. Aerial applications of propanil at 12 to 15 gal/acre give better coverage and control of dense stands of large weeds (6 to 12 inches tall) than lower volumes.

In a field experiment in Arkansas, propanil at 3 lb/acre applied at the proper time with a tractor sprayer at volumes of 5, 10, 20, or 40 gal/acre controlled barnyardgrass effectively at all volumes without rice injury. Conversely, propanil controlled weeds less effectively as the spray volume decreased in experiments in Texas. Propanil at 3 lb/acre applied with a tractor sprayer controlled 99, 90, and 66 percent of the barnyardgrass when applied in water volumes of 10, 8, and 5 gal/acre, respectively. Further research showed that tractor-sprayer applications of propanil at 3 to 5 lb/acre controlled barnyardgrass and other weeds effectively when applied at the correct time at volumes of 15 to 20 gal/acre.

At Stuttgart, Ark., aerial applications of propanil at 3 lb/acre in a 5-gal/acre water emulsion controlled weed grasses less effectively than at the same rate in 10-gal/acre emulsion. In another experiment at Stuttgart, propanil applied by a boom-nozzle aircraft sprayer at 3 or 4 lb/acre in 5 or 10 gal/acre of spray controlled barnyardgrass effectively and did not injure rice. Spray drift, however, appeared to be less with 10 than with 5 gal/acre. In a third experiment at Stuttgart, propanil applied by aircraft with a boom-nozzle sprayer at 3 lb/acre in 10 gal/acre controlled 95 percent of the barnyardgrass, broadleaf signalgrass, and northern jointvetch plants and did not injure rice. Propanil applied by aircraft at the same rate in 3 gal/acre of emulsion with a rotary-atomizer sprayer controlled only 70 to 80 percent of the weeds and injured rice leaves. Adding surfactant L[3] at 2 percent (volume/volume) to the 3-gal/acre treatment increased weed control to 95 percent, but this treatment injured rice leaves severely. Adding surfactant to the 10-gal/acre treatment did not alter the activity of the spray on weeds or rice. Presumably, the surfactant increased foliar retention and penetration of the 3-gal/acre treatment by both weeds and rice plants. The concentration of the propanil in the spray of 3 gal/acre was three times that at 10 gal/acre, which would probably increase the injury by solvents in the formulation.

Method and depth of seeding

Propanil at 2 to 16 lb/acre applied to water- or dry-seeded 'Nato' or 'Bluebonnet 50' rice grown in the greenhouse injured only slightly rice plants in the one- to two-leaf stages of growth, but 32 lb/acre injured rice moderately (table 22). Propanil applied in the field at 3 to 12 lb/acre did not reduce grain yields of 'Bluebonnet 50' rice that was water- or dry-seeded (table 23). This information indicates that field rice plants as well as succulent greenhouse plants are not injured by high rates of propanil.

Propanil properly applied usually controls susceptible weeds in dry- and water-seeded rice. The method of seeding the rice crop does not alter the effectiveness of propanil for weed control, but it does influence the populations of weed species infesting fields. Dry seeding increases problems with weed grasses, and water seeding enhances growth of aquatic and sedge weeds while decreasing grass populations.

[3] Petroleum sulfonate, free and combined fatty acid, and petroleum oil.

TABLE 22.—*Effect of seeding method and depth and rate of propanil applied early postemergence on growth of* 'Nato' *and* 'Bluebonnet 50' *rice in greenhouse conditions, Stuttgart, Ark., 1959*

[Percent injury based on visual rating]

Seeding method and depth	Propanil rate (lb/acre) 0	2	4	8	16	32
'Nato':						
Water-seeded	0	0	0	13	17	60
Dry-seeded, ½ inch	0	20	0	0	13	37
Dry-seeded, 1½ inches	0	0	0	0	13	27
'Bluebonnet 50':						
Water-seeded	0	0	0	0	23	37
Dry-seeded, ½ inch	0	0	0	7	10	43
Dry-seeded, 1½ inches	0	0	0	0	0	13

Rice cultivars

Most rice cultivars grown commercially in the United States tolerate propanil applied at effective rates for weed control. In one field experiment at Stuttgart, Ark., propanil at 3 or 6 lb/acre applied as a postemergence treat-

TABLE 23.—*Yield of* 'Bluebonnet 50' *rice grown in the field as influenced by seeding method and depth and rate of propanil applied early postemergence, Stuttgart, Ark., 1960*[1]

Seeding method and depth	Rough rice yield, untreated plots (lb/acre)	Yield increase, treated plots (pct)[2] Propanil rate (lb/acre) 3	6	12	Average
Water-seeded: Soil surface	5,630	1	2	6	3
Dry-seeded:					
Drill-seeded; 1½ inches	5,310	2	5	4	4
Broadcast-seeded; ½ to 1¼ inches	5,220	8	5	9	7

[1] Rice essentially weed free.
[2] Percentage increase in yield over untreated plots.

ment did not injure the cultivars listed in table 24. Applications of propanil at normal use rates in field experiments and in commercial ricefields have not injured the following cultivars: 'Arkrose', 'Belle Patna', 'Bluebelle', 'Nova', 'Nova 66', and 'Starbonnet' in the South and 'Calrose', 'Colusa', 'Earlirose', and 'CS-M3' in California.

Nitrogen fertilization

Propanil controlled barnyardgrass effectively when urea nitrogen (45 percent N as granules) was applied at any time from the day of herbicide treatment until 15 days after spraying (table 25). None of the treatments injured rice. In field experiments and in commercial ricefields, applications of nitrogen as urea or ammonium sulfate applied any time before or after propanil treatments did not affect the selectivity of propanil to rice or the control of rapidly growing, susceptible weeds 3 inches tall or less.

In field experiments propanil mixed with water injured rice less than propanil applied in nitrogen solution.[4] Rice treated with propanil in 20 gal/acre of nitrogen solution was injured severely within 2 days after treatment, although it recovered after 10 days. Rice treated with propanil in 20 gal/acre of water emulsion was not injured. Nitrogen solution alone at 20 gal/acre injured the leaves of rice and barnyardgrass moderately within 2 days after treatment, but they recovered after 10 days. Propanil mixed with water controlled barnyardgrass better than propanil in mixtures of water and

[4] Contains 45 percent ammonium nitrate, 35 percent urea, and 20 percent water.

TABLE 24.—*Effect of postemergence treatment with propanil on yields of rice cultivars, Stuttgart, Ark., 1960 and 1961*[1]

Cultivar	Rough rice yield (lb/acre)		Yield increase or decrease, treated plots (pct)[3]
	Untreated plots	Treated plots[2]	
'Bluebonnet 50'	5,070	4,950	−2
'Caloro'	5,900	5,760	−2
'Century Patna 231'	5,440	5,530	+2
'Gulfrose'	5,230	4,890	−6
'Nato'	5,800	5,920	+2
'Northrose'	6,270	6,320	+1
'Tainan-iku 487' (PI215936)	6,150	6,080	−1
'Zenith'	5,290	5,100	−4

[1] All plots kept weed free by hoeing.
[2] Plots treated at 3 and 6 lb/acre.
[3] Yields from treated and untreated plots did not differ significantly for any variety at the 5-pct level.

TABLE 25.—*Effect of time of applying urea nitrogen after propanil treatments on barnyardgrass control, Stuttgart, Ark., 1963*

[Propanil applied at 4 lb/acre to 1- to 4-leaf grass, ¼ to 2 inches tall, and to 1- and 2-leaf rice, 2 to 4 inches tall]

Method of grass control	Grass control (pct)[1]				
	Time of urea application after propanil treatment (days)				Average
	0	5	11	15	
Hand-hoed[2]	80	77	82	85	81
Propanil[2]	93	83	78	92	86
Hand-hoed check[3]	..	..	..	..	92
Propanil check[3]	..	..	..	..	86
None (untreated check)[4]	..	..	..	..	7

[1] Measurements made at midseason after grass matured.
[2] Values are averages from plots that received 40 and 80 lb/acre nitrogen at 0, 5, 11, or 15 days after propanil and an additional 40 lb/acre 60 days after rice emergence. Grass control on hand-hoed or propanil-treated plots did not differ significantly at the 5-pct level for all times of nitrogen application.
[3] No nitrogen was applied early, but 40 lb/acre was applied at 60 days.
[4] No propanil or hand hoeing; nitrogen applied as explained in footnote 2.

nitrogen solution or in nitrogen solution alone (table 26).

In another field experiment mixtures of propanil and water or of propanil and nitrogen solution controlled one- to four-leaf barnyardgrass about equally (table 27). Mixtures of propanil and nitrogen solution injured rice more than mixtures of propanil and water, but rice recovered 1 to 2 weeks after treatment. Barnyardgrass with five or more leaves was not controlled by either mixture.

Mixtures of propanil and nitrogen solution controlled barnyardgrass no better and usually injured rice more than propanil and water mixtures. When nitrogen solution is used as the nitrogen fertilizer, an application 1 to 3 days after a propanil treatment should cause fewer complications than an application of both as a tank mixture.

Soil type

Soil type does not affect the activity of propanil on rice or weeds (table 28). Correctly timed propanil applications at 3 to 5 lb/acre to actively growing plants controlled barnyardgrass effectively on Crowley silt loam, Sharkey clay, and Perry clay. Treated rice yielded significantly more grain than untreated. Where barnyardgrass infestations were heaviest, yield increases from the treatments were greatest.

Rainfall and temperature

Rainfall and air temperature affect the herbicidal activity of propanil on weeds. At least 8 hours without rain after propanil treatment is usually required for effective weed control. In experiments at Stuttgart, Ark., when a 2-inch rain occurred 3 and 9 hours after treatment, propanil at 5 lb/acre controlled 40 and 95 percent of the barnyardgrass and treated rice yields were 2,830 and 6,260 lb/acre, respectively. Rain 3 hours after the treatment apparently washed off the propanil before it was absorbed by the weeds and reduced activity.

Best control of barnyardgrass, other weed grasses, and broadleaf weeds by propanil occurs

TABLE 26.—*Effect of nitrogen solution used as a carrier for propanil on barnyardgrass control and rice yields, Stuttgart, Ark., 1963*

[Propanil applied with ground equipment at 3 lb/acre to 1- to 4-leaf grass, ¼ to 2½ inches tall, and to 1- and 2-leaf rice, 1½ to 4 inches tall]

Carrier and spray volume (gal/acre)		Grass control (pct)[2]	Rough rice yield (lb/acre)
Water	Nitrogen solution[1]		
[3]0	...	99	5,870
[4]0	...	0	1,900
20	0	80	5,230
10	10	35	3,420
5	15	42	3,140
0	20	30	2,770
LSD (5 pct)[5]		14	1,290

[1] Plots treated with nitrogen solution alone at 10, 15, and 20 gal/acre were not significantly different from the weedy check in grass control or rice yield at the 5-pct level.

[2] Measurements made at midseason after grass matured.

[3] Hoed check.

[4] Unhoed check.

[5] LSD = least significant difference at level given.

TABLE 27.—*Effect of carrier and of time and rate of propanil treatments on barnyardgrass control, Stuttgart, Ark., 1964*

[Propanil applied in 20-gal/acre emulsion with ground equipment]

Time propanil applied after grass emergence and carrier[1]	Grass control (pct)[2]				
	Propanil rate (lb/acre)				Average[3]
	0	2	4	6	
1 week, water	0	53	70	73	65
1 week, N solution	0	53	73	70	65
2 weeks, water	0	17	37	30	28
2 weeks, N solution	0	20	30	23	24
3 weeks, water	0	0	7	13	7
3 weeks, N solution	0	10	20	13	14
5 weeks, water	0	3	17	23	14
5 weeks, N solution	0	10	27	23	20
7 weeks, water	0	0	10	17	9
7 weeks, N solution	0	0	7	3	3

[1] Stage and height of grass when sprayed: 1 week, 1 to 4 leaves, ¼ to 1½ inches tall; 2 weeks, 1 to 5 leaves to tillering, ¼ to 3 inches tall; 3 weeks, tillering, 2 to 5 inches tall; 5 weeks, tillering and jointing, 8 to 12 inches tall; 7 weeks tillering, jointing, and heading, 12 to 16 inches tall.

[2] Measurements made at midseason after grass matured.

[3] Value for zero rate excluded from average.

TABLE 28.—*Effect of soil type on barnyardgrass control and rice yield in plots treated with propanil, Stuttgart, Ark., 1961*

[Values are averages from plots treated with 3 and 5 lb/acre propanil applied to 1- to 3-leaf grass]

Soil	Grass control (pct)	Rough rice yield (lb/acre)[1] Untreated plots	Treated plots	Yield increase, treated plots (pct)
Crowley silt loam	82	2,610	4,670	79
Sharkey clay	82	3,490	3,850	11
Perry clay	85	2,460	3,350	36

[1] Yields from treated and untreated plots differed significantly at the 5-pct level on all soils.

when daily maximum air temperatures range from 70° to 90° F and daily minimums are above 60° F. Propanil is most active at these temperatures when cloudy weather prevails for several days before and after herbicide treatment. Presumably, cloudy weather retards cuticle development on grass leaves, slows detoxification of propanil in the plant by enzymes (*50*) and decreases evaporation of the herbicide, all of which make the herbicide more effective.

When daily low and high temperatures are below 50° and 70° F, respectively, for a few days just before treatment, propanil treatments are frequently ineffective. Propanil activity may be reduced by temperatures above 95° F. Extremely low and high temperatures slow the growth rate of grass plants, making them less susceptible to propanil. When temperatures are unfavorable for propanil activity, it would be advantageous to delay spraying.

Multiple applications

Flooding ricefields soon after propanil applications may damage rice grown on problem (calcareous, saline, and sodic) soils (*89*). If the water is withheld to prevent rice injury, barnyardgrass and other weeds usually reinfest the field. Sometimes sequential propanil treatments can be used to advantage in these situations. The first treatment of 2 to 4 lb/acre is made when the largest weed grasses are about 2 inches tall; a second treatment of 3 to 4 lb/acre is applied after late-germinating weeds are about 3 inches tall. Flooding is then started as soon as the rice is large enough to tolerate the water.

Sequential propanil treatments also control weed grasses and aquatic weeds on good soils. The first treatment of propanil at 3 to 5 lb/acre applied postemergence to drained fields controls annual grasses 2 to 3 inches tall (table 29).

TABLE 29.—*Effect of sequential propanil treatments applied with ground equipment on control of barnyardgrass and aquatic weeds, Stuttgart, Ark., 1969 and 1970*

Propanil treatment	Weed control (pct) Barnyardgrass 1969	Barnyardgrass 1970	Aquatic weeds[1] 1969	Aquatic weeds[1] 1970
3 lb/acre applied when barnyardgrass was 3 inches tall, but before germination of aquatic weeds	96	92	33	0
4 lb/acre applied when barnyardgrass was 3 inches tall, but before germination of aquatic weeds; 3 lb/acre applied when aquatic weeds were 1 inch tall and after death of barnyardgrass	96	96	85	82

[1] Ducksalad, redstem, and waterhyssop

TABLE 30.—*Effect of time and rate of propanil treatments on barnyardgrass control and rice yields, Stuttgart, Ark., 1963*

[Propanil applied in 20-gal/acre water emulsion with ground equipment]

Propanil applied (days after grass emergence)[1]	Propanil rate (lb/acre) ¾	1	1½	2	2¼	3	4
	Grass control (pct)[2]						
All at 8	.....	.....	.....	35	.....	85	78
½ at 5; ½ at 8	.....	45	.....	89	.....	98	.....
⅓ at 2, ⅓ at 5, ⅓ at 8	60	.....	96	.....	98	100	.....
	Rough rice yield (lb/acre)[3]						
All at 8	.....	.....	.....	4,020	.....	5,180	4,620
½ at 5, ½ at 8	.....	4,210	.....	5,230	.....	5,180	.....
⅓ at 2, ⅓ at 5, ⅓ at 8	4,380	.....	5,360	.....	5,330	5,300	.....

[1] At 2 days grass had 1 leaf (¼ inch tall); at 5 days grass had 1 to 3 leaves (¼ to 1 inch tall); at 8 days grass had 1 to 4 leaves (¼ to 2 inches tall).

[2] Grass control averaged 96 and 0 pct on the hoed and unhoed checks, respectively. Least significant difference at 5-pct level = 23 pct. Measurements made at midseason after grass matured.

[3] Yields from the hoed and unhoed checks averaged 5,200 and 3,150 lb/acre, respectively. Least significant difference at 5-pct level = 670 lb/acre.

TABLE 31.—*Effect of time and rate of ground propanil treatments on barnyardgrass control, Stuttgart, Ark., 1964*

[Propanil applied in 20-gal/acre water emulsion]

Propanil applied (days after grass emergence)[1]	Grass control (pct)[2] Propanil rate (lb/acre) 2	3	4	6	Average
All at 0	25	55	32	62	44
All at 4	88	88	75	88	85
All at 7	82	92	80	88	86
½ at 0, ½ at 4	68	82	65	68	71
½ at 0, ½ at 7	78	88	82	78	82
½ at 4, ½ at 7	68	88	78	85	80
⅓ at 0, ⅓ at 4, ⅓ at 7	85	82	82	73	80

[1] At the zero-day treatment, grass had 1 leaf (¼ to ½ inch tall); at 4 days the grass stage depended on time and rate of previous applications, but generally it had 1 to 2 leaves (¼ to ½ inch tall); at 7 days the grass stage depended on time and rate of previous application, but generally it had 1 to 3 leaves (¼ to 1½ inches tall). Amount of grass present depended on time and rate of previous applications.

[2] Grass control averaged 100 and 0 pct on the hoed and unhoed check plots, respectively. Measurements were made at midseason after grass matured.

If fields are flooded within 1 week after treatment, aquatic weeds may germinate. An additional treatment of propanil at 3 to 4 lb/acre applied to drained fields controls these aquatic weeds.

Multiple applications of propanil at low rates beginning when the first barnyardgrass emerged and ending when the oldest plants had

TABLE 32.—*Effect of time and rate of aerial propanil treatments on barnyardgrass control, Stuttgart, Ark., 1964*

[Propanil applied in 10-gal/acre water emulsion]

Propanil applied (days after grass emergence)[1]	Percentage of grass control[2] at propanil rate (lb/acre) of— 1	1½	2	3
All at 11	...	...	...	80
½ at 1, ½ at 6	50	...	50	...
⅓ at 1, ⅓ at 6, ⅓ at 11	...	65	...	90

[1] At 1 day grass had 1 leaf (¼ to ½ inch tall); at 6 days it had 1 to 3 leaves (½ to 1 inch tall); at 11 days it had 2 and 3 leaves (1 to 2 inches tall).

[2] Measurements made about 1 month after propanil treatments.

TABLE 33.—*Effect of propanil-adjuvant mixtures on rice injury and weed control, Stuttgart, Ark., 1968*[1]

[Propanil and mixtures applied in 10-gal/acre water emulsion when rice had 3 to 5 leaves, 6 to 8 inches tall, and when barnyardgrass had 1 to 3 leaves, ½ to 1½ inches tall]

Mixture and application rate	Percentage area of rice leaves burned at indicated days after treatment		Weed control 12 days after treatment (pct)	
	5	12	Barnyard-grass	Yellow nutsedge
3 lb propanil/acre	10	0	80	50
3 lb propanil + 0.05 gal surfactant L/acre	40	0	95	75
3 lb propanil + 0.46 lb adjuvant D/acre	10	0	95	75
3 lb propanil + 1 gal phytobland oil/acre	40	0	95	70

[1] Data taken from Smith (*108*).

three or four leaves usually controlled weeds no better than a single treatment of 3 or 4 lb/acre applied when the largest grass had three or four leaves (tables 30–32). Multiple treatments applied with ground equipment were more effective than aerial applications, presumably because 20 gal/acre of spray emulsion was used in ground applications while only 10 gal/acre was applied by aircraft. Wind and rain frequently interfered with timely ground and aerial applications of the second and third treatments.

Propanil mixtures with adjuvants

The addition of adjuvants, such as surfactants, phytobland oils,[5] emulsifiable oils, and thickening agents, to spray emulsions of propanil may affect the activity of the herbicide on rice and weeds. In experiments at Stuttgart, Ark., some surfactants mixed with propanil and applied with ground equipment in 20 gal/acre of water emulsion increased rice injury when compared with propanil alone, but others had no effect (*108*). Surfactants A and G[6] increased rice injury, but surfactant L did not. Surfactant L mixed with propanil increased weed control in some experiments, but not in others. Surfactant L increased control of barnyardgrass when applied aerially with propanil in 3 gal/acre of water emulsion (*108*); it increased control of barnyardgrass and yellow nutsedge when applied aerially with propanil in 10 gal/acre of water emulsion (table 33). In 1969 surfactant L did not increase the control of barnyardgrass, but rice treated with propanil plus surfactant L yielded more than rice treated with propanil alone (table 34). Propanil plus surfactant L injured the rice less initially than propanil alone, which may have contributed to this increased yield.

Adjuvant D[7] or phytobland oil,[8] mixed with propanil and applied aerially in 10 gal/acre of water emulsion, increased control of barnyardgrass and yellow nutsedge in 1968, but phytobland oil did not increase control in 1969 compared with a standard treatment of propanil alone (tables 33 and 34). Mixtures of phytobland oil and propanil injured rice more than propanil alone both years. The rice, however, recovered from the initial burn 10 to 12 days after treatment. Mixtures of adjuvant D and propanil did not injure rice any more than the standard treatment of propanil.

In experiments in 1969 through 1971 at Stuttgart, Ark., mixtures of propanil with surfactant L or with phytobland oil applied with

[5] An emulsifiable, highly refined paraffin oil containing 98 percent base oil and 2 percent emulsifier, with a minimum unsulfonated residue of 92 percent. Saybolt viscosity of 77.5 seconds at 100° F.

[6] Surfactant A—polyoxyethylene with ethylene oxide side chains varying in length. Surfactant G—sulfonated alkyl ester in a light petroleum distillate solvent.

[7] Polysaccharide gum mixture.

[8] An emulsifiable, highly refined paraffin oil containing 98 percent base oil and 2 percent emulsifier with a minimum unsulfonated residue of 92 percent. Saybolt viscosity of 77.5 seconds at 100° F.

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TABLE 34.—*Effect of propanil-adjuvant mixtures on barnyardgrass control and rice injury and yield, Stuttgart, Ark., 1969*[1]

[Propanil and mixtures applied in 10-gal/acre water emulsion when rice ranged from 4-leaf to tillering stage, 6 to 8 inches tall, and when barnyardgrass ranged from 2-leaf to tillering stage, 1 to 5 inches tall]

Mixture and application rate	Grass control[2] (pct)	Percentage area of rice leaves burned at indicated days after treatment		Rough rice yield[3] (lb/acre)
		1	10	
4 lb propanil/acre	92	30	0	5270b
4 lb propanil + 0.05 gal surfactant L/acre	92	20	0	5700a
4 lb propanil + 1 gal phytobland oil/acre	92	40	0	5340b

[1] Data taken from Smith (*108*).
[2] Measured 10 days after treatment.
[3] Yields followed by the same letter are not significantly different at the 5-pct level by Duncan's multiple-range test.

ground equipment did not control barnyardgrass any better than propanil-water mixtures (*118*). Propanil at 3 or 6 lb/acre was applied alone or in mixtures with surfactant L (0.5, 1, and 2 percent, volume/volume) or phytobland oil (2.5, 5, and 10 percent, volume/volume) in 20 gal/acre of water emulsion to barnyardgrass in the four-leaf, tillering, or jointing stages of growth. The most important factors were the rate of propanil and the stage of barnyardgrass at treatment. Rates of 3 or 6 lb/acre applied to four-leaf grass or 6 lb/acre applied to tillering grass controlled 80 to 90 percent of it, but neither rate controlled grass in the jointing stage satisfactorily. However, 3 lb/acre applied to tillering grass and 6 lb/acre applied to jointing grass reduced weed competition enough to increase grain yields significantly (by 1,000 to 3,000 lb/acre of rough rice) compared with untreated rice.

Adjuvants added to propanil spray emulsions did not consistently increase the activity of propanil on barnyardgrass. Sometimes adjuvants mixed with propanil increased grass control by 10 to 20 percent compared with propanil alone, but often they failed to increase control at all. Time and rate of applying propanil affected weed control considerably more than the addition of an adjuvant.

Propanil mixtures with other herbicides

Mixtures of propanil and molinate control certain hard-to-kill weeds better than either herbicide alone (R. J. Smith, Jr., unpublished data). This mixture applied early postemergence at 3 lb/acre of each herbicide controlled bearded sprangletop, mexican sprangletop, and spreading dayflower as well as more susceptible weeds such as barnyardgrass, hemp sesbania, and northern jointvetch.

Mixtures of propanil with either benthiocarb or butachlor applied postemergence to weeds 2 to 3 inches tall control weed grasses and broadleaf, aquatic, and sedge weeds that have emerged at treatment and those that germinate for up to 4 weeks after treatment (R. J. Smith, Jr., unpublished data). Because of their residual activity, these herbicide mixtures control weed grasses and aquatic and broadleaf weeds in rice grown on problem (calcareous, saline, and sodic) soils, and flooding can be delayed until the rice is large enough to tolerate it. Weeds that germinate during the drained period are controlled by the residual action of the herbicides. These mixtures control many hard-to-kill weeds, for example, dayflower and sprangletop, better than standard treatments of propanil or molinate.

Interactions with other pesticides

Rice may be injured when certain insecticides and propanil are applied together or within a few days of each other. Carbamate and organophosphate insecticides consistently cause leaf necrosis and kill rice plants when applied as a seed treatment or directly to rice before or after a propanil treatment (*11, 13*). Chlorinated hydrocarbon insecticides applied as a seed treatment or within a few days of a propanil treatment are less phytotoxic to rice than carbamate or organophosphate insecticides.

Parathion at 0.1 and 1 lb/acre injected into water 1 and 8 days after propanil treatment injured rice moderately to severely (table 35). When injected into water at 15 to 22 days after

TABLE 35.—*Effect of propanil and parathion treatments on rice grown in the greenhouse, Stuttgart, Ark., 1964*[1]

Days from propanil to parathion treatment	3 lb/acre propanil,[2] parathion at—		No propanil,[3] parathion at —	
	0.1 lb/acre	1 lb/acre	0.1 lb/acre	1 lb/acre
	Percentage loss in green weight of treated rice compared with untreated rice[4]			
1	53	100	29	76
8	30	60	29	53
15	17	38	2	28
22	14	31	5	13
	Percentage rice leaf chlorosis			
1	40	80	10	30
8	30	60	20	40
15	40	40	10	20
22	20	10	0	10

[1] Data taken from Smith (*108*).
[2] Propanil at 3 lb/acre reduced green weight by 14 pct and caused 20 pct chlorosis, compared with untreated rice.
[3] Parathion applied at comparable times as in the propanil and parathion treatments.
[4] Least significant difference at 5-pct level=11 pct. Measurements made 63 days after seeding.

propanil treatment, it injured rice only slightly to moderately. Parathion at about 0.1 lb/acre injected into the water as ricefields are flooded controls mosquitoes (*69*). Effective mosquito control treatments consist of applying parathion in the first floodwater after propanil treatment.

Mixtures of propanil and carbaryl injure rice moderately to severely and reduce grain yields. In a field experiment at Stuttgart, Ark., a mixture of propanil at 3 lb/acre and carbaryl at 0.5 lb/acre applied to rice 4 inches tall caused 55 percent injury, compared with 5 and 0 percent injury from either propanil or carbaryl, respectively (*108*). In a field experiment at Beaumont, Tex., mixtures of propanil at 4 lb/acre and carbaryl at 1 lb/acre applied early postemergence reduced yields 37 percent compared with those from plots treated with either pesticide alone (*12*).

Carbofuran applied after propanil does not interact to adversely injure rice, but propanil applied after carbofuran does (*127*). Propanil at 4 lb/acre was sprayed on 'Starbonnet' rice

TABLE 36.—*Effect of propanil and carbofuran treatments on rice grown in the greenhouse, Stuttgart, Ark., 1966*[1]

[Carbofuran applied to rice seed as a dressing; propanil applied in 20-gal/acre water emulsion when rice plants had 2 leaves, 4 to 6 inches tall]

Propanil rate (lb/acre)	Carbofuran rate (lb/cwt rice seed)	Percentage rice leaf chlorosis 9 days after propanil treatment
0	0	0
0	.5	0
3	0	0
6	0	0
3	.5	40
6	.5	80

[1] Data taken from Gifford et al. (*42*).

at intervals of 3 to 56 days after applying granular carbofuran at 0.6 lb/acre. Interaction of carbofuran and propanil did not cause chlorosis or necrosis of rice leaves when the insecticide was applied 5 days after the herbicide. Leaf chlorosis and necrosis developed within 7 days after propanil treatment and lasted for 2 to 4 weeks. As the time interval between carbofuran and propanil treatments increased, leaf injury decreased. Older rice recovered more quickly than younger plants.

Mixtures of propanil and carbofuran sprayed directly on young rice plants injured them severely. In greenhouse experiments propanil at 3 or 6 lb/acre applied postmergence injured rice moderately to severely when the seed had been treated with carbofuran (table 36). Neither pesticide applied alone injured rice. In field experiments propanil at 4 lb/acre applied postemergence 1 to 3 weeks after seeding rice treated with carbofuran (0.25 lb/100 lb seed) as a seed dressing injured rice and reduced grain yields (*11*).

Carbamate and organophosphate insecticides, such as carbaryl, carbofuran, and parathion, inhibit the action of the enzyme aryl acylamidase in the rice plant. This enzyme hydrolyzes and detoxifies propanil to 3,4-dichloroaniline and propionic acid (*38, 74*). Different carbamate and organophosphate insecticides affect this enzyme differently. In greenhouse experiments at Fargo, N. Dak., carbaryl reduced the activity of aryl acylamidase by about 90 percent. Organophosphate insecticides inhibit aryl acylamidase less than carbamate insecticides do, but they are still active enough to produce adverse interactions with propanil in rice seedlings (*74*). Chlorinated hydrocarbon insecticides apparently do not inhibit the activity of aryl acylamidase; thus, they usually do not interact adversely with propanil in the rice plant.

Molinate

Molinate controls barnyardgrass and certain sedge and broadleaf weeds without injury to rice (table 12). It does not control broadleaf signalgrass and sprangletop and aquatic weeds, such as ducksalad, false pimpernel, redstem, and waterhyssop. Growth stage of weeds, rate of herbicide, and water management influence the effectiveness of molinate on susceptible weed species.

Molinate, a thiocarbamate herbicide, is slightly soluble in water (1,000 p/m at 68° F) and highly soluble in common organic solvents. It is formulated with organic solvents and emulsifiers as an emulsifiable concentrate or as a granular formulation on clay or other suitable granular carriers. Molinate is rapidly lost by volatilization or by codistillation with water from moist surfaces; volatilization is practically stopped by incorporating it into soil or irrigation water. Soil micro-organisms contribute significantly to the disappearance of molinate herbicides incorporated in soil. When incorporated into warm, moist soil it is normally decomposed 4 to 6 weeks after treatment. Technical molinate has an acute oral LD_{50} of 720 mg/kg for rats, which is low.

Mode of selectivity

Molinate is rapidly metabolized in plants and soils (*36*, *79*, *80*). It may be absorbed by weed seed during the early stages of germination. Seeds that are not germinating apparently do not absorb molinate. It may also be absorbed by roots, coleoptiles, and basal shoot tissue. Some plants absorb molinate more rapidly than others. Excised barnyardgrass coleoptiles absorbed more molinate than rice coleoptiles did (*19*). Once molinate is absorbed into the plant, it rapidly translocates throughout the plant. It accumulates, however, in the meristems of the root and shoot. Molinate is rapidly metabolized in the plant to carbon dioxide metabolites; these are assimilated in natural plant constituents such as organic acids, carbohydrates, cellulose, amino acids, and proteins. Some plant species detoxify thiocarbamates more rapidly than others. For example, mung bean degrades *S*-propyl butylethylthiocarbamate (pebulate), which is chemically similar to molinate, faster than does wheat. Mung bean, therefore, is more tolerant than wheat to thiocarbamates. Probably for the same reason rice is more tolerant than barnyardgrass to molinate. In experiments in California, molinate at 0.3 p/m reduced the length of barnyardgrass shoots 39 percent, but 7 p/m reduced the length of rice shoots only 30 percent (*86*).

Time and rate of application

Granular molinate, applied in the floodwater by aircraft after crop emergence and when barnyardgrass plants are 3 to 6 inches tall, controls barnyardgrass in dry- and water-seeded rice (tables 37 and 38, fig. 3). Rice is usually injured little, if any, by molinate treatments made when grass plants are 3 to 6 inches tall. Ordinarily, 3 lb/acre controls barnyardgrass better than 2 lb/acre, and usually this rate is as effective as 4 or 6 lb/acre. Molinate applied at 4 or 6 lb/acre to tillering rice and barnyardgrass may injure rice and usually controls barnyardgrass less effectively than lower rates applied earlier (table 38). Rice treated with molinate yields more grain than untreated rice when competitive weed grasses are controlled.

Granular molinate at 3 lb/acre applied into the flood suppressed growth of tillering barnyardgrass (plants up to 12 inches tall) and improved rice yields; this was an economical treatment (R. J. Smith, Jr., unpublished data).

In experiments at Biggs, Calif., granular or emulsifiable molinate applied at 3 lb/acre to dry soil immediately before flooding the ricefield and seeding rice controlled barnyardgrass effectively (88 to 96 percent); rice plots so treated yielded 6,670 lb/acre, compared with 1,320 lb/acre for untreated plots (*86*).

Water management

When molinate is applied in irrigation water after the emergence of rice and weed grasses,

TABLE 37.—*Effect of method of seeding rice and time and rate of molinate treatment on rice injury, barnyardgrass control, and rice yield, Stuttgart, Ark., 1964*[1]

Seeding method and time of molinate application[2]	Rice injury[3] (pct)					Grass control[4] (pct)					Rough rice yield (lb/acre)				
	Molinate rate (lb/acre)				Average[5]	Molinate rate (lb/acre)				Average[5]	Molinate rate (lb/acre)				Average[5 6]
	0	2	4	8		0	2	4	8		0	2	4	8	
Dry-seeded:															
Drill, preplanting	0	0	10	40	20	0	40	70	100	70	30	3,740	4,480	4,420	4,210
Drill, postemergence	0	0	0	30	10	0	90	100	100	97	990	5,530	5,580	5,300	5,470
Broadcast, preplanting	0	0	10	40	20	0	90	100	100	97	150	3,690	4,750	4,420	4,280
Broadcast, postemergence	0	0	20	30	20	0	90	100	100	97	1,730	3,240	4,330	3,940	3,840
Water-seeded:															
Preplanting	0	0	0	30	10	40	100	100	100	100	3,330	4,860	3,740	4,990	4,530
Postemergence	0	0	30	50	30	60	100	100	100	100	3,080	4,380	4,130	3,850	4,120
Average[7]	0	0	10	40	..	17	85	95	100	...	1,560	4,240	4,500	4,480	.....

[1] Data taken from Smith (*108*).
[2] Preplanting treatments incorporated into soil just before seeding. Postemergence treatments applied to the floodwater when rice had 1 or 2 leaves and when barnyardgrass had 1 to 3 leaves.
[3] Based on visual rating of growth inhibition.
[4] Measurements made at midseason after grass matured.
[5] Value for zero rate excluded from averages.
[6] Least significant difference at 5-pct level=920 lb/acre.
[7] Least significant difference at 5-pct level for rice yields=470 lb/acre; at 1-pct level, 620 lb/acre.

its effectiveness for control of barnyardgrass is influenced by the number of days that the water remains on the ricefield after molinate application and the length of time that the ricefield remains drained after molinate has controlled the initial weed infestation.

In field experiments at Stuttgart, Ark., barnyardgrass and broadleaf signalgrass, the latter of which is somewhat tolerant to molinate, were controlled more effectively when the flood was maintained for 7 or 12 days after an application of molinate than when it was held only 2 days (table 39). Plots that remained flooded for 12 days after application of molinate yielded

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FIGURE 3.—Control of barnyardgrass in rice with molinate. *Left*, drill-seeded rice treated with granular molinate at 3 lb/acre when barnyardgrass had three or four leaves. *Right*, untreated plot.

TABLE 38.—*Effect of time and rate of molinate treatments on rice injury, barnyardgrass control, and rice yield, Stuttgart, Ark., 1965 and 1967*[1]

Plant height at treatment (inches): Rice	Plant height at treatment (inches): Barnyardgrass	Molinate rate (lb/acre)	Rice injury[2] (pct)	Grass control[3] (pct)	Rough rice yield (lb/acre)[4]
1–5	0.25–2	0	0	0	5720b
		2	0	98	6910a
		3	6	98	6860a
		4	0	94	6640a
		6	0	98	6870a
4–6	1–4	0	0	0	5480b
		2	0	91	6710a
		3	0	95	6980a
		4	0	96	6740a
		6	0	97	6700a
4–8	[5]1–6	0	0	0	4600c
		2	0	76	6600a
		3	0	94	6650a
		4	0	92	7010a
		6	0	95	6740a
[5]6–10	[5]3–10	0	0	0	3810c
		2	4	80	6740a
		3	8	82	6180a
		4	6	90	6340a
		6	14	90	6400a

[1] Data taken from Smith (*112*). 'Bluebonnet 50' and 'Starbonnet' were drill-seeded in 1965 and 1967, respectively.

[2] Based on visual rating of growth inhibition and chlorosis.

[3] Ratings taken at midseason after heading of barnyardgrass.

[4] Yields followed by the same letter are not significantly different at the 5-pct level, by Duncan's multiple-range test.

[5] Largest rice and barnyardgrass plants were tillering.

TABLE 39.—*Control of weed grasses as influenced by length of period flooded after treatment with molinate, Stuttgart, Ark., 1966 and 1967*[1]

Flood period (days)	Weed grass control (pct): Barnyardgrass[2]	Weed grass control (pct): Broadleaf signalgrass[3]
2	70	27
7	86	53
12	96	80

[1] Granular molinate at 3 lb/acre was applied in irrigation water when drill-seeded rice was 7 to 8 inches tall and when weed grasses were 2 to 5 inches tall. Data taken from Smith (*108*).

[2] Average values for 1966 and 1967.

[3] Values for 1967 only.

TABLE 40.—*Barnyardgrass control as influenced by period drained after treatment with molinate, Stuttgart, Ark., 1966 and 1967*[1]

Days kept drained	Barnyardgrass control (pct): 1966	Barnyardgrass control (pct): 1967
0	83	90
5	91	88
10	80	70
20	95	63
29	63	57

[1] Granular molinate at 3 lb/acre was applied in the irrigation water when drill-seeded rice was 2 to 6 inches tall and when barnyardgrass was 0.5 to 3 inches tall. Plots were kept flooded for 7 days after applying molinate and then drained for number of days indicated. Data taken from Smith (*115*).

better than plots drained 2 or 7 days after treatment. This yield increase was attributed to more effective control of weed grasses by the longer flood period.

In other experiments postemergence applications of molinate at 3 lb/acre to flooded rice controlled emerged barnyardgrass and prevented reinfestations (table 40). After molinate had controlled the emerged grass (usually about 7 days after treatment), the flood could be removed for up to 10 days without reinfestation by weed grasses. Barnyardgrass reinfested rice that had been kept drained for 20 or 29 days; these late-germinating plants competed with rice sufficiently to reduce grain yields.

Method of application

Emulsifiable molinate may be applied with tractor or aircraft equipment. Applications by tractor in water emulsion of 15 to 20 gal/acre or by aircraft in 8 to 10 gal/acre, with equipment calibrated and adjusted accurately, control weeds satisfactorily. Emulsifiable sprays or granular formulations applied to dry soil before seeding or granular formulations applied postemergence in floodwater control weed grasses more effectively than emulsifiable sprays applied postemergence in floodwater. Molinate applied before seeding is more effective when it is incorporated into the soil by disking or by flooding immediately after application.

Applications of granular or emulsifiable molinate to dry soil before seeding may be made with tractor or aircraft equipment. Postemergence treatments in floodwater are applied with aircraft equipment. Venturi and rotary spreaders that are accurately calibrated and adjusted provide even distribution of molinate, which results in effective weed control.

Method of seeding

Seeding method may affect the tolerance of rice to molinate. In experiments at Stuttgart, Ark., molinate at 8 lb/acre applied postemergence to flooded, drill-seeded rice or incorporated in the soil before water seeding of rice did not injure rice enough to reduce grain yields (table 37). But the same amount incorporated before drill seeding of rice or applied postemergence to flooded, water-seeded rice injured the crop sufficiently to reduce grain yields. Even when molinate injures rice slightly to moderately, grain yields increase wherever molinate controls weed infestations that would otherwise reduce yields. In experiments at Biggs, Calif., molinate applied at rates as high as 12 lb/acre before flooding controlled weed grasses effectively and did not injure water-seeded rice (*78*). Differences in cultivar, environment, soil, and water depth at the two locations may have contributed to differences in rice susceptability.

Rice cultivars

Commercial rice cultivars respond in the same way to treatments of molinate. Molinate at 2 or 3 lb/acre applied immediately before water seeding of rice or applied in irrigation water soon after emergence of dry-seeded rice injures these cultivars little, if any. In field experiments and in commercial ricefields, 'Bluebonnet 50', 'Bluebelle', 'Bonnet 73', 'Brazos', 'Caloro', 'Dawn', 'Labelle', 'Lebonnet', 'Nato', 'Nova 66', 'Saturn', and 'Starbonnet' were not injured significantly by postemergence treatments of molinate at 3 lb/acre applied in floodwater before rice began tillering (R. J. Smith, Jr., unpublished data). However, these cultivars were frequently injured by molinate at 6 lb/acre.

Soil type

Soil type has little influence on the effectiveness of molinate for control of barnyardgrass. Molinate controls barnyardgrass effectively when applied to clay, clay loam, and silt loam soils. However, soil type may affect injury of rice from molinate treatments. Rice grown on clay was injured less by postemergence treatments applied in floodwater than rice grown on silt loam.

Temperature

Low temperatures affect the activity of molinate on barnyardgrass less than they influence the activity of propanil. In a growth-chamber experiment at Stuttgart, Ark., molinate and propanil, each at 3 lb/acre, were applied to barnyardgrass plants 1 to 2 inches tall grown at low (75° day and 55° F night) and high (88° day and 70° F night) temperatures. Granular molinate was applied to flooded plots, but propanil was sprayed on unflooded plots to simulate the way these herbicides are normally applied to commercial ricefields. At the low temperatures molinate reduced growth of grass 100 percent, compared with only 75 percent for propanil. At the high temperatures both herbicides controlled 97 percent of the barnyardgrass. Neither herbicide injured rice at either temperature regime, but the rice grew faster at the higher temperatures.

In field experiments and in commercial ricefields molinate controlled barnyardgrass effectively when night temperatures were as low as 45° F and day temperatures were as low as 60° F. Propanil usually fails to control barnyardgrass when temperatures are this low.

Sequential applications with propanil

Sequential treatments of propanil and molinate control barnyardgrass better than either herbicide applied alone. Propanil applied postemergence controls plants 2 to 3 inches tall. Additional barnyardgrass may germinate and infest the ricefield if irrigation water is not applied within 5 days after the propanil treatment. These infestations are controlled with 2 or 3 lb/acre of molinate applied after the ricefield has been flooded. When propanil is used instead of molinate, the ricefield has to be drained before the second treatment. Molinate can be applied directly in the irrigation water, so the cost of draining and reflooding the ricefield for a second herbicide treatment is avoided.

Interaction with other pesticides

Molinate and other pesticides, such as insecticides and fungicides, do not interact to adversely affect rice or alter the effectiveness of molinate on weeds. In field experiments in Louisiana, tank mixtures of molinate at 4 lb/acre and insecticides such as carbofuran or fensulfothion, each at 1 lb/acre, did not affect rice adversely (*42*). Field observations indicate that molinate and insecticides such as aldrin, parathion, and carbaryl or fungicides such as cyano(methylmercuri)guanidine and thiram do not interact unfavorably on rice or weeds.

Phenoxy Herbicides

Postemergence treatments of 2,4-D, MCPA, 2,4,5-T, and silvex control many aquatic, broadleaf, and sedge weeds, but not weed grasses (table 12). They are applied at rates of 0.25 to 1.5 lb/acre of acid equivalent. The rate depends on the formulation to be applied, the weed species, stage of growth of the rice, air and water temperatures, and perhaps other conditions.

Phenoxy herbicides usually are formulated and marketed as two basic types—salts and esters. Salt formulations are available as amines, such as diethanol amine, triethanol amine, dimethyl amine, triethyl amine, and isopropyl amine, and as alkali-metal salts, such as lithium, potassium, and sodium. Amine salts are available chiefly as water-soluble liquids, and inorganic salts are available as water-soluble powders; both types are practically nonvolatile.

Esters of phenoxy herbicides are high or low in volatility. The highly volatile esters include the methyl, ethyl, isopropyl, butyl, and amyl. The low-volatility esters include the butoxyethanol, butoxyethoxypropanol, capryl, ethoxyethoxypropanol, isooctyl, and propylene glycol butyl ether. These esters of 2,4-D, MCPA, 2,4,5-T, and silvex are liquids that, when properly formulated, form oil-in-water or water-in-oil emulsions. Low-volatility esters are less likely to vaporize and drift to susceptible crops than highly volatile ones when temperatures are 95° F or less. When temperatures exceed 95° F, even the low-volatility esters may vaporize, drift, and injure susceptible crops. States that produce rice prohibit the use of highly volatile esters, but low-volatility esters are permitted in some States for weed control in rice. Silvex, 2,4-D, 2,4,5-T, and MCPA range from low to intermediate in acute oral toxicity (LD_{50}=300–1,000 mg/kg for rats) (*79*).

Mode of selectivity

The herbicidal action of phenoxy herbicides in plants has been discussed frequently (*22*, *67, 79*). Entry and translocation of phenoxy herbicides occur through leaves, stems, and roots of rice and weeds. They are translocated from sites of absorption to sites of action. The movement of phenoxy herbicides may be upward into young leaves, downward into young roots, or to meristems anywhere in the plant. Kind of plant, growth stage of plant, rate of plant growth, environment, and soil—all affect the responses of plants to phenoxy herbicides.

Phenoxy herbicides affect many interacting plant processes to cause death of plants. Effective herbicidal action involves penetration of plant membranes, absorption and assimilation by cells, translocation through tissues and by the vascular system, and finally a toxic action usually involving the living protoplasm (*22*). Experiments show that the herbicidal action of phenoxy herbicides may be influenced by each of these physiological and biochemical processes and that the herbicides in turn affect the processes. At lethal rates, phenoxy herbicides upset the balance between production and use of plant foods. Respiration increases and photosynthesis decreases, with the consequent depletion of carbohydrates. Plants treated with phenoxy herbicides may also contain high levels of phytotoxic breakdown products.

Phenoxy herbicides induce structural changes in plants. After treatment, plants may become desiccated and brittle, or they may develop malformed and twisted leaves, stems, roots, and inflorescences. Typical responses of sensitive plants to phenoxy herbicides include cell enlargement, increased cell division, development of malformed tissue, production of numerous root primordia in the stem, and finally death.

Stage of rice growth

The stage of growth greatly influences the response of rice plants to phenoxy herbicides. Very young rice (from emergence up to 3 weeks after emergence) may be injured severely or even killed by phenoxy herbicides at rates required to control weeds. Rice treated at the early-tillering, late-jointing, booting, or heading stages also may be seriously affected. Rice in the late-tillering to early-jointing stages is usually not injured by phenoxy herbicides. The tolerant stage can be positively identified when the basal internode begins to elongate from 0.25 to 0.5 inch long. Rice may be injured when the internode is longer than 0.5 inch. Most commercial U.S. varieties of rice are tolerant at this stage of development regardless of maturity-group classification. For very-short-season varieties ('Bluebelle', 'Belle Patna') this tolerant stage usually occurs 5 to 6 weeks after emergence; 7 to 9 weeks for short-season varieties ('Nato', 'Nova 66'); and 8 to 10 weeks for midseason varieties ('Starbonnet', 'Bluebonnet 50', 'Toro'). The California varieties ('Calrose', 'Caloro', 'Colusa', and 'CS-M3') reach this tolerant stage from 7 to 8 weeks after seeding. In a 6-year investigation at Stuttgart, Ark., 2,4-D applied at 0.75 and 2 lb/acre to rice in the early-tillering and booting stages reduced yields substantially, but applications in the late-tillering and early-jointing did not (table 41).

Kind of phenoxy herbicide

Rice responds differently to different kinds of phenoxy herbicides. When rice is in the early-tillering stage of growth, 2,4,5-T and silvex are less phytotoxic than 2,4-D or MCPA (table 41). MCPA is even less toxic than 2,4-D when applied during early stages of growth. Silvex and 2,4,5-T did not reduce rice yields when applied at early-tillering, late-tillering, and early-jointing stages of growth. However, all these phenoxy herbicides reduced yields when applied during the booting stage.

Several characteristic injury symptoms appear when rice is injured by phenoxy herbicides. Rice treated with 2,4-D at the early-tillering stage grows tubular leaves ("onion leaf" symptoms) and malformed panicles (fig. 4), but rice treated with MCPA, 2,4,5-T, and silvex at the same stage appears normal. All these herbicides applied at any stage may injure roots moderately to severely, may cause the plant to turn dark green soon after spraying early-tillering rice, or cause chlorosis or downward positioning of the leaves if applied to booting or heading rice. Treatments of phenoxy herbicides may affect plant height and bushel weight of rough rice (table 42) or delay rice maturity.

Weeds also respond differently to the different kinds of phenoxy herbicides (table 12).

TABLE 41.—*Effect of time of application of phenoxy herbicides on rice yields, Stuttgart, Ark., 1955–61*

[Values are averages from plots treated with 0.75 and 2 lb/acre of phenoxy herbicides]

Herbicide and stage of rice[1]	Change in yield (pct/acre)[2]						
	1955	1956	1957	1958	1959	1961	Avg.
2,4-D:							
Early-tillering	−13	−20	−24	−16	−4	−27	−17
Late-tillering	+1	−6	+22	+5	+8	−4	+4
Early-jointing	−10	−9	+12	−2	−8	...	−3
Booting	−14	−18	−21	−19	−9	−17	−16
LSD (5 pct)[3]	8	8	21	10	12	8	11
2,4,5-T:							
Early-tillering	...	...	−7	+2	+7	−1	0
Late-tillering	...	...	−5	+13	+4	−2	+2
Early-jointing	...	...	+3	+2	−4	...	0
Booting	...	...	−21	−14	−14	−29	−20
LSD (5 pct)[3]	...	...	21	10	12	8	13
MCPA:							
Early-tillering	...	...	−20	−7	...	...	−14
Late-tillering	...	...	−2	−3	...	...	−2
Early-jointing	...	...	+1	+3	...	...	+2
Booting	...	...	−7	−19	...	...	−13
LSD (5 pct)[3]	...	...	21	10	...	...	15
Silvex:							
Early-tillering	...	...	+2	−2	+11	...	+4
Late-tillering	...	...	−10	−2	+2	...	−3
Early-jointing	...	...	0	−2	+6	...	+1
Booting	...	...	−18	−4	−11	...	−11
LSD (5 pct)[3]	...	...	21	10	12	...	14

[1] 2,4-D, 2,4,5-T, and MCPA formulated as amines. Silvex formulated as the propylene glycol butyl ether, ester. Herbicides applied about 5, 8, 11, and 14 weeks after rice emergence for the early-tillering, late-tillering, early-jointing, and booting stages, respectively.

[2] Yield expressed as percentage reduction (−) or increase (+) as compared with untreated weed-free plots. Yields for untreated plots were 3,710, 3,500, 4,430, 3,820, 4,300, and 5,700 lb/acre for 1955 to 1961. The 6-year average yield for untreated plots was 4,240 lb/acre.

[3] LSD=least significant difference at level given.

Hemp sesbania is very susceptible to 2,4-D and 2,4,5-T (fig. 5), but northern jointvetch is somewhat resistant to 2,4-D and susceptible to 2,4,5-T (table 43). Ducksalad, however, is more susceptible to 2,4-D than to 2,4,5-T (table 44). Where several species of weeds varying in susceptibility to a herbicide are present, mixtures of phenoxy herbicides are often more effective than one herbicide used alone.

Formulations

Silvex is applied as an ester because this formulation controls weeds better than amine or inorganic salts. Inorganic salts of 2,4-D, 2,4,5-T, and MCPA, such as sodium, potassium, and lithium, are less effective on weeds than amine or ester formulations. Esters usually control weeds better than amines.

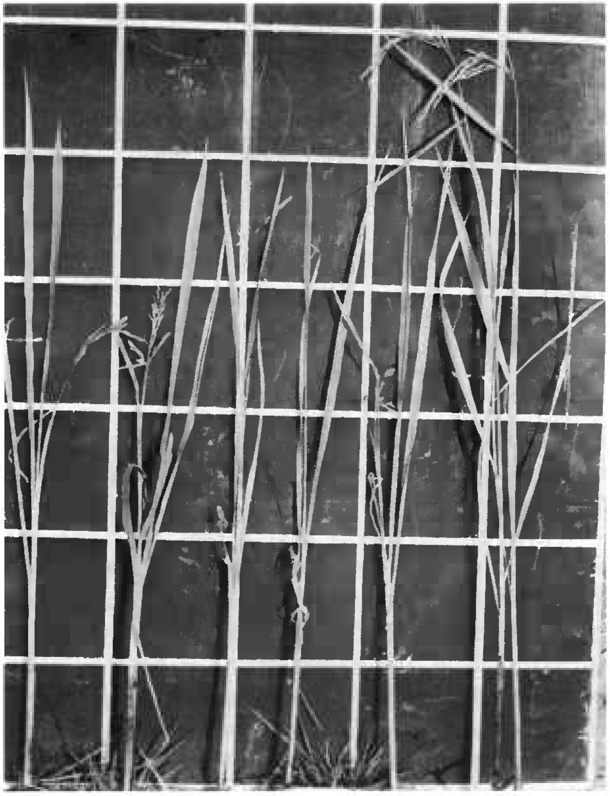

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FIGURE 4.—Two untreated plants (*right*) and rice with malformed leaves and panicles caused by injury from 2,4-D applied at the early-tillering stage of growth (*left*).

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FIGURE 5.—Control of hemp sesbania with phenoxy herbicides in rice. *Left*, plot sprayed with 2,4-D at 1 lb/acre at midseason. *Right*, unsprayed plot.

Rice is most tolerant to all formulations of phenoxy herbicides during the late-tillering and early-jointing stages of growth. However, at susceptible stages of growth, esters frequently are more toxic than amines. Amines of 2,4-D

TABLE 42.—*Effect of time of application of phenoxy herbicides on plant height and bushel weight of rice, Stuttgart, Ark., 1957–59*

[Values are averages from plots treated with 0.75 and 2 lb/acre of phenoxy herbicides]

Herbicide[1]	Stage of rice when treated: Early-tillering	Late-tillering	Early-jointing	Booting
	Percentage change in height of mature rice plants[2]			
2,4-D	−3	+1	+2	+2
2,4,5-T	0	+1	+5	+12
MCPA	−2	−1	+2	+5
Silvex	+2	0	+4	+10
LSD (5 pct)[3]	3	3	3	3
	Percentage change in bushel weight[4]			
2,4-D	0	−0.2	+1.0	−0.9
2,4,5-T	+0.6	+.4	+.2	−1.7
Silvex	+4	+.2	0	−1.1
LSD (5 pct)[3]	.9	.9	.9	.9

[1] 2,4-D, 2,4,5-T, and MCPA applied as amines. Silvex applied as the proplyene glycol butyl ether ester.

[2] Expressed as percentage reduction (−) or increase (+) as compared with untreated weed-free check. Values are averages of 3 years of data, 1957–59. Average height for untreated plots was 44.8 inches for 2,4-D, 2,4,5-T, and silvex comparisons, and 44.4 inches for MCPA comparisons.

[3] LSD = least significant difference at level given.

[4] Expressed as percentage reduction (−) or increase (+) as compared with untreated weed-free plots. Values are averages of 1 year of data, 1959. Average bushel weight for untreated plots was 46.2 lb.

TABLE 43.—*Control of hemp sesbania and northern jointvetch with 2,4-D and 2,4,5-T, Rohwer, Ark., 1960 and 1962*

Herbicide[1]	Weed control (pct): Hemp sesbania 1960	1962	Average	Northern jointvetch 1960	1962	Average
2,4-D	95	98	96	25	30	28
2,4,5-T	100	95	98	75	95	85
2,4-D + 2,4,5-T	100	..	..	100	..	..

[1] Applied postemergence at midseason as amines: 2,4-D and 2,4,5-T applied at 1 lb/acre; 0.5 lb/acre each of 2,4-D and 2,4,5-T applied in a mixture.

and 2,4,5-T, formulated as water-in-oil or invert emulsions, have been developed to control aquatic, broadleaf, and sedge weeds in rice. These formulations are more active on weeds and drift less than regular ester or amine formulations (*88*). Invert emulsions are applied with specially designed equipment.

Although invert emulsions, properly applied, drift less than regular emulsions or water-soluble sprays, their sprays can drift sufficiently to damage nontarget susceptible crops. In experiments in Texas (*88*) invert emulsions sprayed aerially had only 0.1 percent of the spray volume composed of droplets smaller than 200 micrometers. By comparison, regular, or oil-in-water, emulsions had 30 percent of the spray volume composed of droplets smaller than 200 micrometers. In other experiments in Texas, invert emulsions sprayed aerially had less than 1 percent of spray volume deposited beyond 100 feet downwind from the treated area, compared with 18 percent for regular emulsion sprays.

In experiments in Arkansas, invert emulsion sprays of 2,4-D or 2,4,5-T at 0.5 to 1 lb/acre applied by aircraft controlled weeds effectively with only slight rice injury. The treatments caused brown spots on rice leaves, but the rice recovered within 2 weeks after treatment. A herbicide-water spray volume of 4 to 8 gal/acre applied in spray droplets that ranged from 200 to 1,000 micrometers in diameter covered weeds and drifted little if any.

Granular formulations of phenoxy herbicides frequently control aquatic, broadleaf, and sedge weeds less effectively than sprays.

Method of seeding and water management

When phenoxy herbicides are applied at 0.25 to 1.5 lb/acre during tolerant stages of rice, the method of seeding and water management usually do not influence the response of rice to these herbicides. Seeding method and water management may significantly affect the response when the herbicides are applied in susceptible stages, especially rice 3 to 6 weeks old. When water-seeded rice 3 to 6 weeks old is to be sprayed with phenoxy herbicides, a shallow flood on the ricefield reduces damage. The stage of rice development at the time of applying phenoxy herbicides, however, is much more important than seeding method or water management.

TABLE 44.—*Control of ducksalad with 2,4-D and 2,4,5-T, Stuttgart, Ark., 1958–60*

Herbicide and application rate[1]	Ducksalad control (pct)			
	1958	1959	1960	Average
2,4-D:				
1 lb/acre	80	100	...	90
2 lb/acre	83	100	80	88
2,4,5-T:				
1 lb/acre	13	25	...	19
2 lb/acre	47	75	30	51

[1] Applied postemergence at midseason as amines.

Water management may affect the response of weeds to phenoxy herbicides. If water covers low-growing aquatic weeds such as ducksalad, redstem, purple ammannia, or waterhyssop at spraying time, the weeds may not be controlled because the herbicide does not contact them. If weeds are growing slowly because of dry soil, control may be poor. When draining of the ricefield begins 3 to 6 days before herbicide treatment, weeds are exposed to the herbicide, and soil moisture is sufficient for rapid growth of weeds.

Nitrogen fertilization

When phenoxy herbicides are applied at the tolerant stages of rice development, the time of applying nitrogen fertilizer often affects the response of rice to the herbicides. Rice may be injured when nitrogen is applied 10 to 15 days before or 10 to 15 days after the herbicides.

At Stuttgart, Ark., applications of nitrogen 15 days before the herbicide stimulated growth of rice in 4 or 5 days. At the time herbicides were applied, rice was green and growing rapidly. The herbicides caused chlorosis and reduced yields. The rice was not injured when nitrogen was applied from 5 days before to 5 days after the herbicide, but yields were reduced when nitrogen was applied 15 days after applying a phenoxy herbicide in the tolerant or early-jointing stage.

Phenoxy herbicides applied to rice in the early-jointing stage when basal internodes range from 0.25 to 0.5 inch long injure rice little, if any, when some nitrogen is applied within 5 days after treatment. Indeed, nitrogen may help the rice recover from the herbicide injury.

Environmental factors

In greenhouse experiments rice treated with 2,4-D, MCPA, and 2,4,5-T was injured more when subjected for 3 days (2 days before and 1 day after herbicide treatment) to 97° F than when subjected to 62° or 72° F (*61*). Rice 2 to 8 weeks old exposed to a temperature of 97° F was injured severely by these herbicides, but as the rice grew older than 2 weeks, injury decreased. At 97° F rice was injured most by 2,4-D, followed by MCPA and 2,4,5-T in decreasing order.

The effect of temperature in increasing the activity of phenoxy herbicides on rice is greatly influenced by the rate of plant growth at different stages of rice development. Even when rice is treated during the tolerant stages, high temperatures may increase rice injury by phenoxy herbicides if plants have received untimely applications or excessive rates of nitrogen and are growing rapidly. The stage of development and rate of growth of the rice plant at time of herbicide treatment are more important than temperature before, at, or after treatment.

Weeds respond best to phenoxy herbicides when temperatures range from 70° to 90° F. Temperatures below 60° F during the week before treatment may slow weed growth and reduce herbicide activity. Temperatures above 95° F before treatment may increase superficial contact injury by the herbicide and reduce its absorption, which in turn would decrease its efficacy on the weeds.

Rainfall within 3 hours after postemergence treatments of phenoxy herbicides may reduce weed control, because the herbicides may be washed from the plant before it is absorbed. Phenoxy herbicides usually control weeds effectively if rain occurs no sooner than 6 hours after treatment. Ester formulations resist washing from weed plants more than amine or inorganic salt formulations.

Moderate to high relative humidities (ranging from 60 to 90 percent) increase the effectiveness of phenoxy herbicides. The humidity is usually in this range in ricegrowing areas when phenoxy herbicides are applied. Rice is usually sprayed in the early morning or late afternoon and sometimes it is sprayed at night. At these times the relative humidity is higher than at other times of the day.

Spray volume and method

Phenoxy herbicides are applied with low-gallonage sprayers mounted on tractors or aircraft. Spray volumes of 5 to 15 gal/acre for tractor application or 3 to 10 gal/acre for aircraft treatments usually cover weeds sufficiently for satisfactory control. Regardless of the equipment used, weeds are controlled only when the herbicides contact the weeds and are absorbed by them.

Sequential applications with other herbicides

Sequential treatments of phenoxy herbicides with propanil or molinate frequently control weed grasses and aquatic, broadleaf, and sedge weeds more effectively than a treatment of only one herbicide. Propanil at 3 to 5 lb/acre or molinate at 3 lb/acre applied at early postemergence controls young weed grasses. When aquatic, broadleaf, or sedge weeds infest the ricefield after flooding, 2,4,5-T or silvex applied to drained fields at 0.5 to 1 lb/acre 2 to 3 weeks after the propanil or molinate treatment controls aquatic weeds that are less than 2 inches tall with only slight injury of rice. The ricefield is flooded again within 5 days after the phenoxy herbicide treatment.

More aquatic, broadleaf, and sedge weeds may germinate after early applications of these herbicides. If they become a problem at midseason another phenoxy herbicide treatment with either 2,4,5-T, silvex, 2,4-D, or MCPA can be applied during the tolerant stage of rice growth.

Interaction with other pesticides

Phenoxy herbicides and other pesticides, such as insecticides and fungicides, do not interact to adversely affect rice or alter the effectiveness of phenoxy herbicides on weeds. Rice treated with aldrin, thiram, or cyano(methylmercuri) guanidine as seed dressings is not injured by postemergence treatments of phenoxy herbicides applied to rice in the tolerant stage. Rice treated with postemergence applications of insecticides such as carbaryl, carbofuran, and parathion is not damaged by proper postemergence treatments of phenoxy herbicides.

Copper Herbicides

Copper sulfate

Copper sulfate (pentahydrate) at 0.5 p/m by weight of copper (approximately 2 lb copper sulfate per 4 acre-inches of water) applied in irrigation water as soon as algal colonies form on the soil frequently controls green and blue-green algae in ricefields and irrigation systems and does not injure rice (*87*). It is more effective against green than against blue-green algae, and it does not control chara or aquatic, broadleaf, and sedge weeds or weed grasses (table 12). It is most effective when applied to acid soils low in organic matter or to water low in carbonate or bicarbonate salts. These salts in the soil-water medium inactivate copper sulfate by forming insoluble basic copper carbonates. Copper sulfate at concentrations as low as 0.33 p/m by weight in the water may injure fish. If water with copper sulfate is drained from the ricefield into irrigation systems, fish, shellfish, and other aquatic animal life may be injured. Quick-dissolving, fine-mesh (32–100 mesh) copper sulfate is applied aerially in California to control the tadpole shrimp (*Triops longicaudatus* Le Conte), which damages rice seedlings.

Copper complexes

Chelated copper formulations such as copper-triethanolamine complexes control green and blue-green algae more effectively than copper sulfate (R. J. Smith, Jr., unpublished data). These formulations are not inactivated as easily as copper sulfate by carbonate and bicarbonate salts. A rate of 0.75 to 1 lb/acre of elemental copper controls blue-green algae in ricefields when applied 1 to 3 days after permanently flooding the rice. It is most effective when applied as soon as algal colonies form on the soil; if applications are delayed until colonies form a floating mat, control may be poor. Treatments applied aerially in 3 to 5 gal/acre of solution kill the algae within 2 to 5 days of application.

New Experimental Herbicides

Benthiocarb

Benthiocarb applied at 3 to 4 lb/acre or tank mixtures of benthiocarb and propanil at 3 or 4 lb benthiocarb/acre and 3 lb propanil/acre control many weed grasses and aquatic, broadleaf, and sedge weeds 2 to 3 inches tall and those that germinate for up to 4 weeks after treatment. Benthiocarb at 4 lb/acre applied after the soil has been sealed by rain or irrigation and just before emergence of weeds and rice controls many weeds effectively and does not injure rice. Because benthiocarb alone and in mixtures with propanil controls weeds residually, it is effective for weed control in rice grown on problem soils. Flooding immediately after treatment is not required to prevent reinfestation of weed grasses.

Benthiocarb alone or mixed with propanil sprayed early postemergence injures dry-seeded rice only slightly, but such treatments may damage water-seeded rice. However, granular formulations applied at 2 to 3 lb/acre 10 to 20 days after seeding controlled aquatic weed complexes and did not injure water-seeded rice. Benthiocarb-propanil mixtures control weed grasses, including barnyardgrass, broadleaf signalgrass, and sprangletop, and aquatic weeds such as dayflower, ducksalad, redstem, and waterhyssop. Benthiocarb alone frequently fails to control broadleaf signalgrass and broadleaf weeds such as morningglory, northern jointvetch, and hemp sesbania.

In California, applications of benthiocarb at rates as low as 3 lb/acre made 10 to 14 days after water seeding controlled barnyardgrass, bearded sprangletop, and ducksalad effectively. There was no significant rice injury at rates as high as 12 lb/acre. Applied before flooding, benthiocarb controlled weeds ineffectively at rates less than 6 lb/acre, but this rate controlled barnyardgrass effectively. In most instances where benthiocarb controlled weed grasses at

3 or 6 lb/acre, control of California arrowhead, roughseed bulrush, and creeping spikerush was very poor. Soil incorporation practically eliminated the herbicidal activity of either emulsifiable or granular formulations applied at 3 or 6 lb/acre before flooding and water seeding of rice.

Oxadiazon

Oxadiazon applied at 0.5 to 1.25 lb/acre or tank mixtures of propanil at 2 or 3 lb/acre and 0.5 to 0.75 lb/acre of oxadiazon control many weed grasses and aquatic, broadleaf, and sedge weeds 2 to 3 inches tall and those that germinate for up to 4 weeks after treatment. Oxadiazon applied after the soil has been sealed by rain or irrigation and just before emergence of weeds and crop controls many weeds effectively and is adequately selective for rice. Oxadiazon is somewhat more phytotoxic to rice than benthiocarb. If water stands on treated rice, oxadiazon may reduce rice populations and inhibit early growth of the crop. This herbicide is selective on dry-seeded rice but not on water-seeded rice.

Oxadiazon alone and in mixtures with propanil applied postemergence controls weed grasses, including barnyardgrass, broadleaf signalgrass and sprangletop, aquatic weeds such as dayflower, ducksalad, redstem, and waterhyssop, and broadleaf weeds such as hemp sesbania and northern jointvetch. Morningglory species are not effectively controlled.

Butachlor

Tank or formulated mixtures of butachlor and propanil applied at 3 lb butachlor/acre and 3 or 4 lb propanil/acre control many weed grasses and aquatic, broadleaf, and sedge weeds 2 to 3 inches tall and those that germinate for 4 or 5 weeks after treatment. Because of its residual activity, butachlor is very effective for controlling weeds in rice grown on problem soils. When the mixture is used on problem soils, flooding can be delayed until the rice is large enough to tolerate the water or for up to 4 weeks after emergence; weed plants that germinate during the drained period are controlled by the residual action of butachlor. Because the mixture controls weeds during the critical early part of the growing season on all soils, subsequent treatments with propanil, molinate, or phenoxy herbicides often are not required.

Butachlor and propanil mixtures applied early postemergence injure dry-seeded rice little, if any, but they may damage water-seeded rice. These mixtures control weed grasses such as barnyardgrass, broadleaf signalgrass, and sprangletop. They control many aquatic weeds such as dayflower, ducksalad, redstem, and waterhyssop that are not controlled by propanil or molinate. However, some broadleaf weeds, such as morningglory, northern jointvetch, and hemp sesbania, are not controlled.

KN_3 and NaN_3

Sequential treatments of propanil and KN_3 or NaN_3 control weed grasses and aquatic, broadleaf, and sedge weeds in dry-seeded rice in the South *(110)*. Propanil applied at early postemergence controls grass weeds 2 to 3 inches tall. Small aquatic weeds that germinate after treatment with propanil and after flooding are controlled with granular KN_3 and NaN_3 at 3 to 4 lb/acre applied in the floodwater about 2 weeks after the propanil treatment; weeds 1 to 2 inches tall are most susceptible. KN_3 or NaN_3 alone fails to control weed grasses and broadleaf weeds. They control aquatic weeds such as ducksalad, redstem, waterhyssop, and false pimpernel, however, that have emerged at treatment and those that germinate for up to 10 days after treatment, provided the water is held at a depth of 2 to 4 inches. Additional aquatic weeds may germinate after this period. If the rice stand is good, these late-germinating weeds usually do not compete significantly with rice.

Sequential treatments of molinate and KN_3 or NaN_3 control many weed grasses and aquatic weeds in dry-seeded rice in the South. Granular molinate at 3 lb/acre applied in the floodwater after emergence of the crop and weed grasses controls barnyardgrass and other annual weed grasses. Small aquatic weeds, 1 to 2 inches tall, that germinate after molinate treatment and flooding are controlled with granular KN_3 or NaN_3 applied in the water. KN_3 and NaN_3

treatments applied about 2 weeks after a molinate treatment have the same limitations as those following a propanil treatment.

Granular KN_3 or NaN_3 applied at 3 to 4 lb/acre in floodwater 15 to 20 days after water seeding controls many aquatic weeds in the South. Aquatic weeds less than 2 inches tall, such as ducksalad, false pimpernel, fimbristylis, redstem, and waterhyssop, are controlled without injury to rice; however, waterhyssop and spikerush are less susceptible than the others. Since KN_3 and NaN_3 do not control weed grasses, a propanil or molinate treatment may be combined with the azide treatment if weed grasses are problems in water-seeded rice.

In dry- and water-seeded rice, KN_3 and NaN_3 do not injure young rice plants growing in a favorable environment, but they may injure seedlings growing under adverse conditions. Rice growing on problem soil during periods of cool temperatures is especially susceptible.

Bifenox

Granular bifenox applied at 2 or 3 lb/acre just before or just after permanent flooding controls germinating aquatic weeds and does not injure rice. Bifenox treatments applied sequentially with propanil or molinate effectively control most grass and aquatic weeds all season. Although preemergence sprays of bifenox injure rice moderately, they control bearded and other species of sprangletop. Propanil treatments applied postemergence control barnyardgrass and broadleaf weeds that escape bifenox treatment.

Bentazon

Bentazon applied at 0.5 to 1 lb/acre controls spreading dayflower and many species of smartweed and does not injure rice. It controls spreading dayflower plants from 3 to 12 inches tall and smartweeds from 2 to 6 inches tall. Propanil or molinate treatments, applied sequentially with bentazon, control grass, broadleaf, and sedge weeds that escape bentazon treatment.

Bioherbicide

An endemic anthracnose disease of northern jointvetch incited by the fungus *Colletotrichum gloeosporioides* (Penz.) Sacc. f. sp. *aeschynomene* was discovered in 1969 at Stuttgart, Ark. (*28*). Water sprays of the fungus spores at 2 million spores/ml in 10 gal/acre controlled 95 to 100 percent of the northern jointvetch plants in field trials. The fungus controlled plants in the bloom stage of growth, up to 5 feet tall. The disease developed on northern jointvetch most rapidly at temperatures between 70° to 90° F and at relative humidities above 80 percent; the ricefield environment is ideal for development of the disease on weed plants. An incubation period of 4 to 7 days and up to 5 weeks is usually required to kill the weeds. The fungus is very virulent on northern jointvetch and only slightly virulent on Indian jointvetch. It does not affect rice, soybeans, or cotton or common field forage and vegetable crops or other weeds.

Commercial ricefield application in 1973 and 1974 demonstrates that an endemic fungus can be used effectively to control a severe weed. Research and development will determine if the fungus can be produced in sufficient quantities for general use for control of northern jointvetch.

EQUIPMENT FOR WEED CONTROL

Herbicides are applied to rice by hand and tractor sprayers and by fixed-wing aircraft and helicopter sprayers (figs. 6 and 7). Aerial equipment is used more often than ground equipment because timely and quick applications can be made when the soil is too wet to support a tractor. In addition, levees are obstacles for tractors.

HAND SPRAYERS

Several types of hand sprayers are used in rice, including regular and constant-pressure knapsack sprayers. If uniform and accurate herbicide applications are required, the constant-pressure knapsack sprayer is best. It consists of two tanks, one for the spray solution and the other for compressed air or other compressed gases. The tanks are connected with a hose through an air-pressure regulator that keeps the gas pressure constant in the liquid tank. The knapsack sprayer can be calibrated for applying herbicides at precise rates.

TRACTOR SPRAYERS

Tractor-mounted boom sprayers, the most common type, consist of a power-takeoff-driven pump, tank or tanks, solution delivery hose, pressure regulator, pressure gage, nozzles, strainers, and booms. Boomless sprayers are sometimes used over rough terrain and where even distribution of spray is not essential.

Pumps.—Several types of pumps, including centrifugal, piston, gear, roller, and rubber impeller, are available for spraying herbicides. They are rated in gallons per minute of discharge at specific speeds. The capacity of the pump is about twice that of the total nozzle delivery rate; this provides adequate flow through the bypass line for hydraulic agitation in the tank.

Tanks.—Tanks are available in mild steel (such as oil drums), stainless steel, aluminum, and plastic reinforced with fiberglass. Much of the trouble with clogged nozzles is caused by rust and scale that accumulate in oil-drum tanks between spraying seasons. The other three materials are more expensive than mild steel, but they withstand the corrosive action of most herbicides. Nozzle stoppage is much less when tanks are constructed of corrosion-resistant materials.

Hoses and connections.—A durable and strong spray hose, resistant to sunlight, oil, and chemicals, is usually used for spraying herbicides. A hose made of neoprene or base rubber combined with tough rayon and nylon cord gives good service. Hose connections are made of corrosion-resistant materials and have inside diameters large enough to avoid restrictions in the lines.

Pressure regulators.—Two types of bypass pressure regulators are generally used for low-volume, low-pressure spraying. One type consists of a spring over a ball and seat; the other consists of a spring, diaphragm, plunger, and seat. Both types have an adjusting screw to regulate pressure. Sometimes a pressure-reducing regulator is used in conjunction with the bypass pressure regulator. The bypass valve may be set at 10 to 15 lb above the desired pressure at the nozzle tips. The reducing regulator may then be set to maintain a uniform pressure on the nozzle tips even though the pump may cause some fluctuation in the delivery pressure at the bypass valve.

Pressure gages.—Accurate pressure gages are essential for delivery of herbicides at precise rates and volumes. They are placed in the hose between the pressure regulator and the delivery nozzles. Gages with a range of 0 to 100 lb/in^2 are satisfactory. A dial scale with 1- or 2-lb divisions facilitates easy and accurate calibration of the sprayers.

Nozzles.—Broadcast booms used for spraying rice are usually fitted with fan nozzle tips that produce a heavy center spray. The size of the nozzle is determined by the particular spraying job. The manufacturer's guide may be consulted for information.

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FIGURE 6.—Application of 2,4-D to rice for control of broadleaf weeds with a fixed-wing airplane sprayer.

Booms.—Broadcast spray booms are classed as wet or dry. A pipe or metal tube transports the liquid in the wet boom. Usually a pipe coupling or eyelet fitting is welded or placed around small holes spaced 18 to 20 inches apart in the pipe. The materials used for making the boom are resistant to corrosion to prevent nozzle stoppage. In the dry boom the supporting member does not carry the liquid. The liquid is transported by hoses and fittings, which consist of pipe tees bolted to the supporting frame. This type of boom is very satisfactory because corrosion is minor, and straightening the boom after accidental bending does not cause leaks.

Strainers.—Line and nozzle-tip strainers are used in the sprayer to remove solid particles that may clog nozzle tips. Usually 50- or 100-mesh screens are satisfactory. All strainers are removed, cleaned, and inspected for holes every few days while in use.

FIXED-WING AIRPLANE SPRAYERS

Most airplane sprayers are equipped with booms and nozzles that are similar to those on tractor sprayers. Other distribution systems include rotation brushes or screens, disks, hollow propellers, bifluid and foam nozzles, and the venturi type. The latter may be a single large unit under the fuselage or several small units mounted under each wing. The boom distribution system is usually used for spraying herbicides on rice.

Granular herbicides are applied aerially with the venturi type or with rotating disks. The distribution device is located under the fuselage and the chemical hopper.

The same types of pumps used with tractors are used with airplanes, but the centrifugal pump is most common. The pump is mounted outside the fuselage and driven by power take-off from the engine or by a small propeller. With the latter, the size of the propeller may be changed for the desired volume of spray. The capacity of the pump is about twice the nozzle output. This allows sufficient liquid through the bypass valve for hydraulic agitation.

Tanks are usually made of corrosion-resistant materials, such as aluminum or fiberglass, and they carry 90 to 250 gallons of herbicide mixture. Pressure regulators, pressure gages, hoses, and strainers used for aerial spraying are similar to those used on tractors.

Booms are usually made of a corrosion-resistant material such as aluminum. To mini-

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FIGURE 7.—Application of 2,4-D to rice for control of broadleaf weeds with a helicopter sprayer.

mize drift of spray, the boom is placed as far below the wing as is practical, usually about 1 foot, and is extended within about 2 feet of the wingtip. If the boom extends to the wingtip, the spray may be whirled upward in the wingtip vortexes to cause excessive spray drift.

Nozzles for fixed-wing aircraft sprayers are made of corrosion-resistant materials such as aluminum, brass, or nylon. Each is equipped with a quick-cutoff diaphragm, screen, and jet. Spray droplet size is greatly affected by the angle at which the nozzles discharge into the airstream. Smaller droplets occur when the nozzles are directed against or across the airstream than when they are directed with it. Droplet size is also affected by pump pressure and nozzle-orifice diameter. Most ricegrowing States have regulations that specify the maximum operating pressure for aerial spraying of phenoxy herbicides; this usually does not exceed 20 lb/in^2. A compromise is usually made between small droplets, which give thorough coverage but have a tendency to drift, and large ones, which settle fast but do not give adequate coverage. Sprays usually give adequate weed control if droplets range from 100 to 300 micrometers in diameter.

Spray pattern, or distribution, is important. Proper placement and spacing of nozzles along the boom helps to distribute the spray evenly. Usually the spray pattern is improved if more nozzles are placed on the right side of the plane than on the left. The air is swirled from right to left by the counterclockwise rotation of the propeller (facing the propeller). Spraying the proper swath width for the particular aircraft also improves spray distribution. The wingspan and the flying height of the airplane govern the swath width. The width of the swath is usually about equal to the wingspan of the plane. Proper flying height improves spray pattern and reduces spray drift. Spray distribution is best when fixed-wing airplanes fly at 10 to 15 feet above the crop, but spray drift is less when they fly at 5 to 10 feet. Phenoxy herbicides are released at the lowest possible height, but propanil or molinate is released at a height that gives best spray distribution.

Example 1.—Calibration of Tractor Sprayer Discharge Rate

1. Select an area for a test run that is similar to the field to be sprayed. Measure off a distance of 660 feet.
2. Place the sprayer on level ground and fill the spray tank with water. Make sure it is full.
3. Spray the 660-foot test run. Operate the sprayer at exactly the same pressure and tractor speed that will be used in the field—usually about 3 or 4 miles per hour.
4. Upon reaching the 660-foot mark, stop spraying. Then measure carefully the number of quarts needed to refill the tank.
5. Convert the number of quarts to gallons of water required to refill the spray tank by dividing by 4. Then multiply this figure by 66. Divide the results by the width, in feet, of the strip sprayed. The answer obtained is the number of gallons of spray liquid the sprayer will apply on 1 acre when it is operated at the same settings.
6. Suppose the sprayer boom sprayed a strip 30 feet wide. After 660-foot strip is sprayed, 10 quarts are required to refill the tank. Ten quarts divided by 4 equals 2.5 gallons. Multiply 66 by 2.5, which equals 165. Then divide 165 by 30 (the width in feet of the sprayed strip). The answer is 5.5, which is the gallons of spray liquid applied per acre.

HELICOPTER SPRAYERS

Helicopters are sometimes used to apply herbicides to rice, but they are more expensive than fixed-wing aircraft. Some users claim that spray applications from helicopters provide better coverage and control of weeds than do those from fixed-wing planes because the downwash from the helicopter rotors forces the spray down into the crop. In closely bounded fields a helicopter can be used advantageously to give better weed coverage near the edge of the ricefield and to reduce spray drift to nearby susceptible crops. The helicopter can stay within the ricefield while turning at the ends of the field. This eliminates flight over nearby susceptible crops and thus prevents accidental contamination of these crops by spray trailing the aircraft or by leakage of spray.

Boom sprayers are used on helicopters. The pumps, tanks, hoses, pressure regulators, pressure gages, nozzles, booms, and strainers used on helicopters are similar to those used on fixed-wing planes.

A helicopter carries about 60 gallons of liquid spray in two spray tanks; one is located on each side of the aircraft for balance. The flying height is usually 2 to 5 feet above the rice. The swath width is about equal to the length of the boom.

Example 2.—Calibration of Airplane Sprayer Discharge Rate

1. Measure off a distance of 1 mile (5,280 feet).
2. Fill the spray tank with water. Make sure it is full.
3. When the weather is similar to that which will prevail while spraying the rice, spray the 1-mile test run. Operate the sprayer at exactly the same pressure and airplane speed (ground speed) that will be used in the field—usually about 80 to 85 miles per hour for fixed-wing planes and about 40 miles per hour for helicopters.
4. Upon reaching the 1-mile mark, cut off the sprayer. Measure carefully the gallons of water needed to refill the tank.
5. Multiply the number of gallons of water needed to refill the tank by 8.25. Divide the results by the width, in feet, of the strip sprayed. The answer obtained is the gallons of spray liquid the sprayer will apply on 1 acre when it is operated at the same settings.
6. Suppose the strip sprayed is 33 feet wide. After the 1-mile strip is sprayed, 12 gallons are required to refill the tank. Multiply 12 by 8.25, which equals 99. Then divide 99 by 33 (the width in feet of the sprayed strip). The answer is 3, which is the gallons of spray liquid applied per acre.

CALIBRATION OF TRACTOR AND AERIAL SPRAYERS

Proper calibration of sprayers is essential for good results with herbicides. Too much herbicide can injure the crop; too little will not control the weeds.

First, select the kind of nozzle that will give the desired volume of spray per acre. In rice, herbicide solutions are applied at low rates—5 to 20 gal/acre by tractor and 1 to 15 gal/acre by aircraft. Each nozzle of a sprayer must discharge uniformly. Check this by measuring the volume of water discharged by each nozzle in 1 minute. Replace or clean nozzles that vary excessively in volume discharged.

After initial selection and adjustment of the spraying equipment, determine the actual per-acre output of the sprayer by making a trial run. This is done by spraying a measured strip of land with water at the tractor or airplane speed that best suits the contemplated job. The amount of water used in the run is measured, and the per-acre discharge rate is calculated as illustrated in examples 1 and 2. Once this is done, the area that can be covered by one tankful of spray is calculated by dividing the capacity of the tank by the sprayer discharge rate, as illustrated in example 3. Finally, calculate the amount of commercial herbicide and water needed to make the desired strength of liquid spray for the size of tank as illustrated in example 4.

Example 3.—Calculation of Area Covered by One Tank of Spray

Problem: Your tank holds 90 gallons. The sprayer is calibrated to apply 3 gal/acre (example 2). How many acres will 1 tank cover?

Calculation: Divide tank capacity by sprayer discharge rate: $90 \div 3 = 30$ acres covered by 1 tank.

Example 4.—Calculation of Herbicide-Water Ratio

Problem: To kill ducksalad infesting a ricefield requires 1.5 lb/acre of 2,4–D acid equivalent. Your tank holds enough to cover 30 acres at a 3-gal/acre rate (example 3). The commercial 2,4-D formulation you are using contains 4 lb/gallon of acid equivalent. How much commercial 2,4-D formulation is required per tank to achieve a 1.5 lb/acre 2,4-D application?

Calculation: Multiply the number of acres 1 tank will cover (30) by the required herbicide rate (1.5 lb/acre). Divide the answer by the acid equivalent in the commercial formulation (4 lb/gal). $30 \times 1.5 = 45$ pounds of 2,4-D required per tank. $45 \div 4 =$ 11.25 gallons of commercial 2,4-D formulation required per tank.

Mix 11.25 gallons of commercial formulation with enough water to fill the tank, and the spray is ready to use.

It is advisable to check the spray distribution pattern of both tractor and aerial sprayers. This may be done by placing water-soluble dye in the tank. Place a strip of white paper on the ground across the swath to be sprayed and, operating the tractor or aerial sprayer exactly as it will be operated in the field, make a test spray run. The spray pattern will be shown on the paper. Height, nozzle, and other adjustments may be required to obtain the desired spray pattern.

Slight pressure adjustments may be required to obtain the desired output of liquid spray. Each time the sprayer is readjusted, it should be recalibrated as described. It is a good idea to make frequent checks for nozzle orifice wear and other factors that may change the rate of spray output.

WEEDS THAT CAUSE ECONOMIC LOSSES IN RICE

Accurate weed identification is essential to control because weeds differ in their response to various herbicides and cultural practices (tables 9 and 12). Only weeds that cause major losses in U.S. rice production are described in this section, although there are others that reduce yields. They are listed alphabetically by common name. The background board in some pictures is marked in 6-inch squares.

GREEN AND BLUE-GREEN ALGAE

Principal genera.—The green algae (Chlorophyceae) include *Chara* spp. (fig. 8) and filamentous *Hydrodictyon* spp., *Pithophora* spp., and *Spirogyra* spp. The blue-green algae (Cyanophycaea) include *Anabaena* spp., *Lyngbya* spp., *Nostoc* spp., and *Phormidium* spp., which frequently form "scum" in ricefields.

Description.—Algae reproduce vegetatively by cell division and by spores. Vegetative reproduction is characterized by accidental separation of colonies or filaments. These small units are distributed by flowing water; they establish new colonies by cell division. The microscopic seedlike spores may be carried by wind and flowing water. Each spore germinates and develops into a new plant much like a seed develops into a plant.

Chara algae are large species that anchor themselves to bottom mud. Symmetrically branched from evenly spaced, cylindrical leaf whorls at the nodes, the plants are usually encrusted with calcareous deposits that give them a coarse, gritty feeling. When crushed, they emit a musky odor similar to garlic or skunk. Usually gray-green, they may have a slightly different color owing to calcareous deposits and accumulated dead plants.

Hydrodictyon algae develop as saclike nets. Numerous small units can be observed growing on the mud and debris in canals in the initial stages of development. These cylindrical sacs, which contain thousands of cells arranged in a mesh, may elongate into heavy masses of growth.

Pithophora algae are irregularly branched and filamentous. Initially, the plants grow on mud and debris in irrigation systems, but the dense growth of later development captures gases that raise mats of plants to the water surface. These floating mats often resemble wet wool, with individual strands of growth resembling coarse thread.

Spirogyra algae grow in long threadlike filaments. Normally bright green, they may be coated with a rust-colored deposit from iron in the water. Typically the chloroplasts can be observed under the microscope as elongated spiral bands extending from one end of the cell to the other; they are embedded in the layer of cytoplasm just inside the cell wall.

Anabaena, Lyngbya, Nostoc, and *Phormidium* algae are filamentous and usually grow in colonies resembling tufts of soft wool. These colonies develop on mud after spore germination. A gelatinous material around the filaments collects gases liberated in growth, and after the gas bubbles accumulate in the colony, small units float to the water surface, where they continue to grow. Typically, the algal units unite to form a solid mass of scum, or "jellyballs," on the water surface. The bottom layer of the scum is covered with soil, but the surface, exposed to air and sunlight, drys to a tough film. Development of scum is usually rapid and varies with soil and environmental conditions.

Distribution.—Green and blue-green algae are troublesome in all rice-producing areas. *Chara* spp. grow in ricefields where stands are thin, in barrow ditches, and in irrigation systems. Green filamentous algae, such as the species of *Hydrodictyon, Pithophora,* and *Spirogyra,* grow most abundantly in irrigation and drainage canals and ditches, where they impede waterflow, but they may enter ricefields from canals and reduce the growth and tillering of young rice plants. Blue-green filamentous

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FIGURE 8.—Chara (*Chara* sp.).

algae, such as the species of *Anabaena, Lyngbya, Nostoc,* and *Phormidium,* are most abundant early in the growing season in newly flooded ricefields. They are especially troublesome in water-seeded rice. Algal growth pulls young rice plants down into the water or mud, thus reducing the stand. Tillering of the rice plants is reduced because the young tillers cannot penetrate the scum. Rice plants may become diseased where they contact the scum, probably from fungi and bacteria in it.

ALLIGATORWEED

Alternanthera philoxeroides (Mart.) Griseb.

Other name.—Alligatorgrass.

Description.—Alligatorweed (fig. 9) is an aquatic and terrestrial perennial that reproduces vegetatively. The stems, 3 to over 24 inches long and often hollow, grow prostrate on water or soil. They are glabrous except at the leaf axils and sometimes near the tips. The nodes usually have two buds, each of which may sprout to produce a shoot. Roots may form at every node in water or on moist soil. On soil the roots enlarge and thicken; they look like the roots of perennial terrestrial plants. The leaves are opposite, narrowly elliptical to lanceolate or oblanceolate, 1 to 5 inches long, and about 0.25 to 1 inch wide; they taper at the base to a very short petiole or are sessile, and have distinct midveins. From 6 to 20 white, chaffy flowers in cloverlike heads are borne on axillary peduncled spikes. Viable seeds have not been found in the United States.

Distribution.—Alligatorweed probably grows in a wider range of water and soil conditions than any other plant. When it grows as a rooted terrestrial plant along the banks of canals and creeks and in cultivated fields, it has a deep and extensive root system. Plants also grow in free-floating mats; if such plants contact unflooded soil, they root. Emersed plants may grow from mud up through 9 feet of water. Alligatorweed grows in and along irrigation systems and in ricefields in the South. Small isolated infestations have been found in southern California, but not in rice-growing areas. Because alligatorweed responds vigorously to fertilization, it grows especially well in fertilized, moist ricefields, where it reduces yields, interferes with harvesting, prolongs drying, and impedes the flow of water in canals and ditches.

ARROWHEAD

Sagittaria spp.

Other names.—Swamp-potato and arrowheadlily.

Principal species.—*S. montevidensis* Cham. & Schlecht. (fig. 10), *S. latifolia* Willd., called common arrowhead, *S. cuneata* Sheldon, *S. graminea* Michx., and *S. calycina* Engelm., called California arrowhead.

Description.—Perennials that reproduce by seed, underground rhizomes, and tubers, arrow-

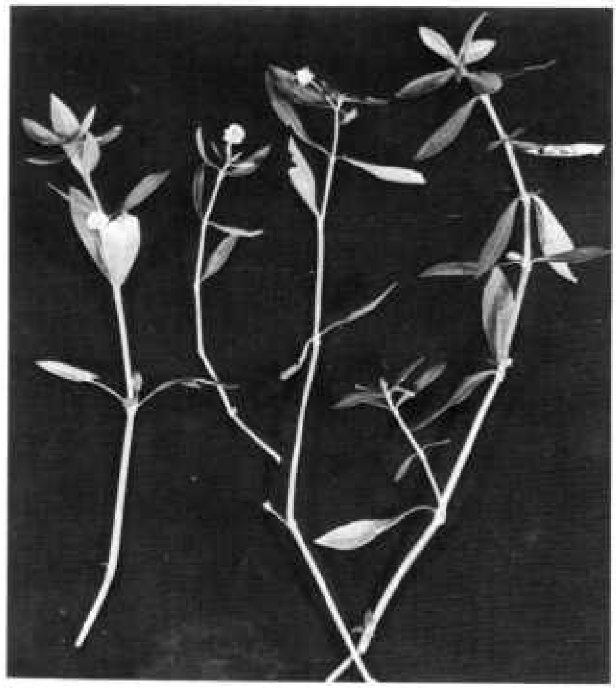

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FIGURE 9.—Alligatorweed (*Alternanthera philoxeroides*).

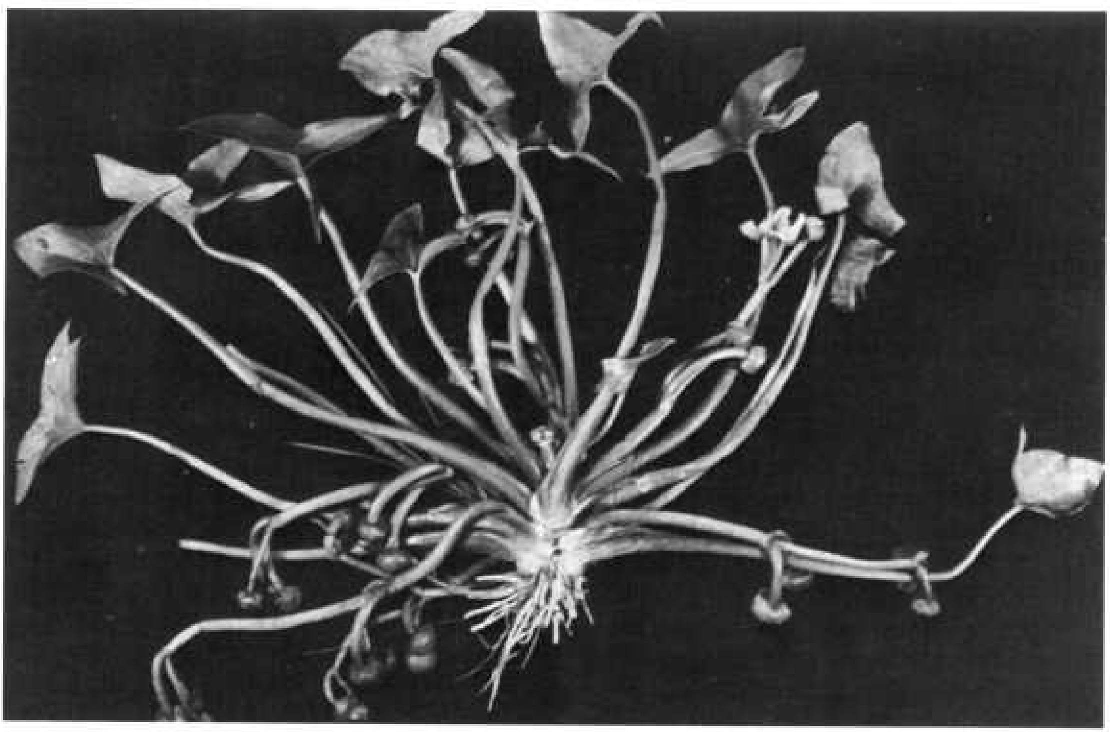

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FIGURE 10.—Arrowhead (*Sagittaria montevidensis*).

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FIGURE 11.—Mature barnyardgrass (*Echinochloa crus-galli*).

heads are rooted aquatics, usually emersed. The common species have arrow-shaped leaves, but some species have linear ones. The normal leaves are all basal, with petioles usually as long as the water is deep. Plants are normally 1 to 2 feet tall.

Distribution.—Arrowheads grow in all rice-producing States, and several species grow in most States. They grow in shallow water in irrigation and drainage canals, in ricefields where stands are thin, and in ricefield barrow ditches.

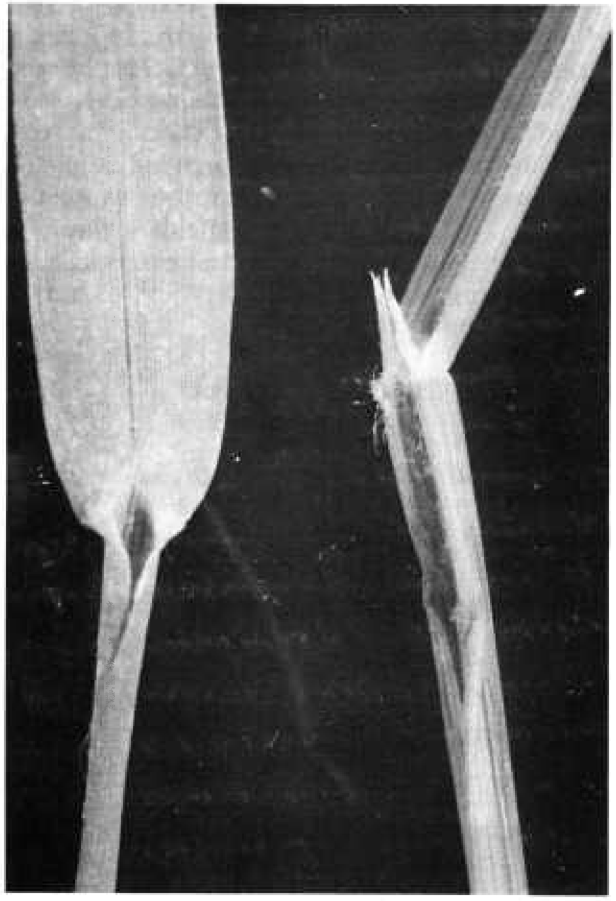

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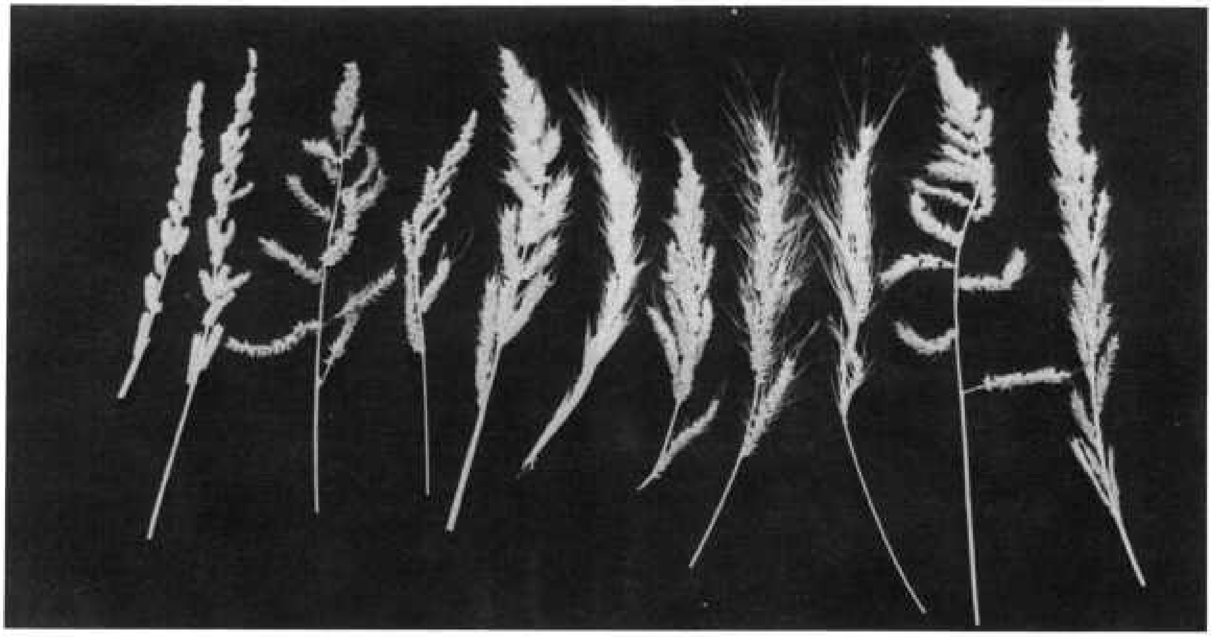
FIGURE 12.—Collar region of barnyardgrass (*left*) and of rice (*right*). Barnyardgrass has no ligule or auricle; rice has ligules and hairy auricles.

BARNYARDGRASS

Echinochloa spp.

Principal species, varieties, and common names.—*E. crus-galli* (L.) Beauv. (fig. 11), called watergrass, millet, bluestem, and baronetgrass; *E. colonum* (L.) Link, called junglerice, little barnyardgrass, and shortmillet; and *E. crus-pavonis* (H.B.K.) Schult., called gulfcockspur and cattailgrass. There are many varieties of *E. crus-galli*, including *zelayensis* (H.B.K.) Hitchc., *longiseta* (Trin.) Farw., and those commonly known as baronetgrass and white barnyardgrass.

Description.—Species and varieties of barnyardgrass that infest ricefields are annuals; they reproduce by seed. Species differ greatly. All species tiller abundantly and produce abun-



PN-4949

FIGURE 13.—Panicles of several varieties of barnyardgrass (*E. crus-galli*).

dant seed that may remain viable in the soil for many years. Young barnyardgrass plants often are difficult to distinguish from rice. The collar region on the leaves may be used to differentiate them. Barnyardgrass has no ligules or auricles; rice has membranous ligules and hairy auricles (fig. 12).

E. crus-galli has more intraspecific morphological variation than most other species. It is erect to decumbent and from 3 to 6 feet tall at maturity. Some varieties are awnless; others have awns, the length of which is characteristic of each. Varieties differ greatly in time to mature, height, and size of stems, heads, and seeds. (Panicles of several varieties of *E. crus-galli* are shown in fig. 13.) Whereas white barnyardgrass, which grows in California, germinates under water, most varieties do not.

E. colonum is prostrate to erect and from 1 to 2 feet tall at maturity. Compared with *E. crus-galli*, it branches more at the base, grows more openly, and has smaller culms, heads, and seeds.

E. crus-pavonis is erect or sometimes decumbent and about 3 to 4 feet tall at maturity, with large conspicuous panicles. The spikelets have long awns.

Distribution.—*E. crus-galli* is a troublesome weed in all ricegrowing States. *E. colonum* and *E. crus-pavonis* grow mostly in Louisiana and Texas, but *E. crus-pavonis* is not common even in these States. All species grow well in rice, on levees, along irrigation and drainage canals, on reservoir banks, in sloughs, and in other wet areas. Barnyardgrass also grows in row crops such as soybeans, corn, and cotton. Seed may be spread by irrigation water, animals, birds, crop seed, farm machinery, and other carriers. Barnyardgrass infestations greatly reduce rice yields.

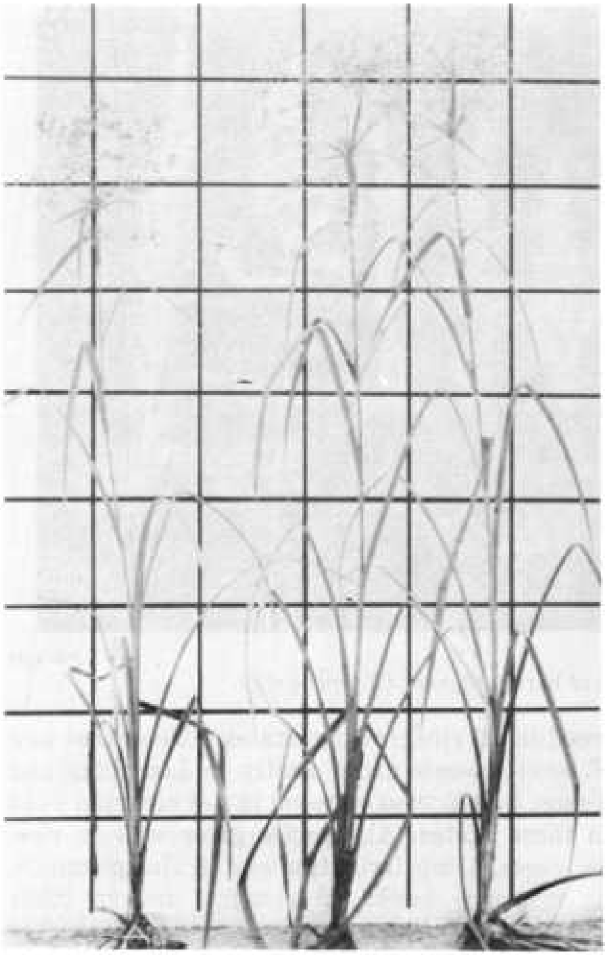
BEAKRUSH

Rhynchospora corniculata (Lam.) Gray

Other names.—Spearhead, hornedrush, umbrellaweed, tadpole-sedge, and ace-of-spades.

Description.—Beakrush (figs. 14 and 15) is a perennial that reproduces by seeds and rhizomes. The stems are stout, leafy, and triangular and from 2 to 6 feet tall. The leaf blades have a rough margin. The inflorescence is widely branched. The seeds are about 0.25 inch long, have beaks 0.5 to 0.75 inch long, and are extremely difficult to separate from rice seed.

Distribution.—Beakrush is a troublesome



PN-4950

FIGURE 14.—Mature beakrush (*Rhynchospora corniculata*).

weed in the South. It grows in ricefields, canals, ditches, and other wet areas. Infestations in rice reduce yields, interfere with harvesting, prolong drying, and reduce quality.

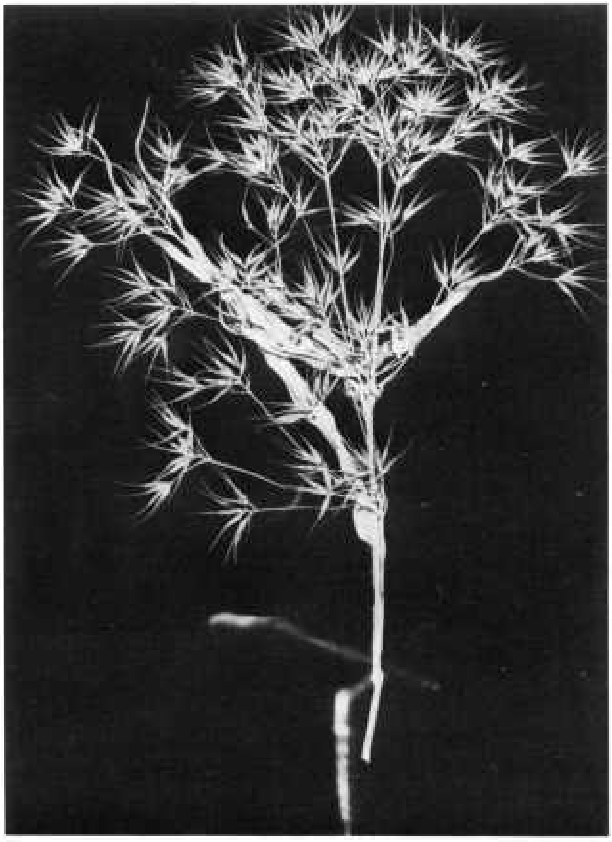
BROADLEAF SIGNALGRASS

Brachiaria platyphylla (Griesb.) Nash

Other names.—Brachiaria and signalgrass.

Description.—Broadleaf signalgrass (fig. 16) is an annual that reproduces by seed. The young plants are similar to crabgrass (*Digitaria* spp.) seedlings, but they have shorter, wider leaves. The seeds are about twice as large as crabgrass seed. The plants are about 1 to 2 feet tall at maturity.

Distribution.—Broadleaf signalgrass grows only in the South—in rice, on levees, and along edges of canals. It reduces yields by competing with rice early in the growing season.



PN-4951

FIGURE 15.—Beakrush panicle.

BULRUSH

Scirpus spp.

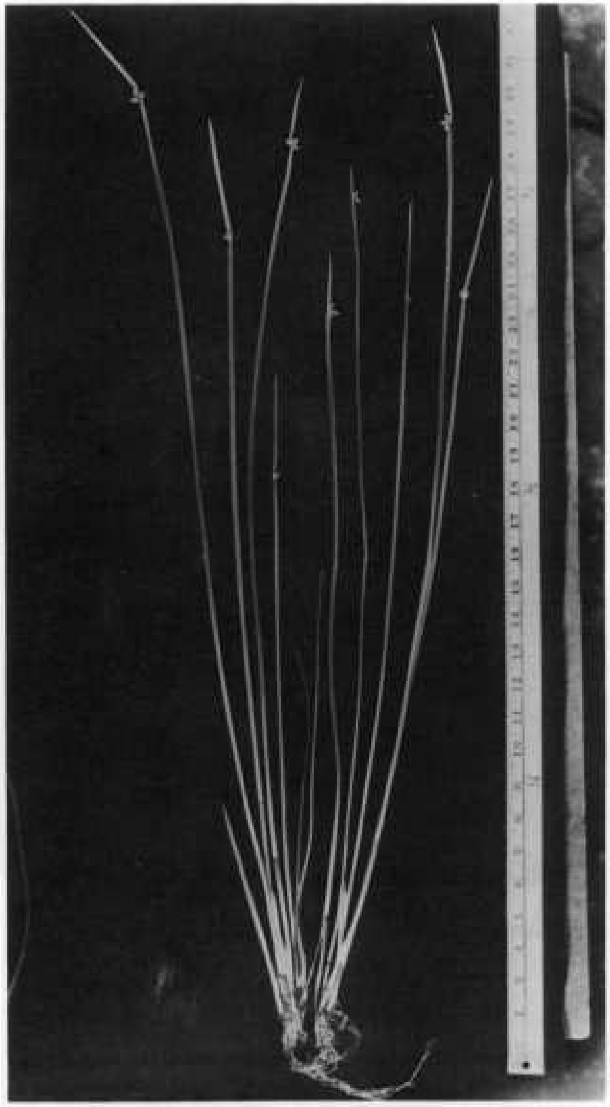
Principal species and common names.—*S. mucronatus* L. (fig. 17), called roughseeded bulrush; *S. fluviatilis* (Torr.) Gray, called river bulrush; and *S. acutus* Muhl. (fig. 18), called hardstem bulrush and great bulrush.

Description.—Most of the bulrushes that are troublesome in rice are perennials, reproducing by seed, rhizomes, or rootstocks. *S. mucronatus* and *S. fluviatilis* have triangular, stout culms that grow 2 to 4 feet tall. *S. acutus* has round, erect culms from 3 to 6 feet tall.

Distribution.—Bulrushes are troublesome in most rice-producing States. *S. mucronatus* and *S. fluviatilis* are problems only in California,

PN-4952

FIGURE 16.—Broadleaf signalgrass (*Brachiaria platyphylla*).



PN-4953

FIGURE 17.—Roughseed bulrush (*Scirpus mucronatus*).

and the former is more troublesome because it infests large acreages of rice. Bulrushes in the South may infest poorly drained ricefields, drainage and irrigation canals, ditches, reservoirs, and other wet areas. In competing with rice, they lower yields, interfere with harvest, and impede the flow of water in canals and ditches.

BURHEAD

Echinodorus cordifolius (L.) Griseb.

Other names.—Mudbabies and creeping waterplantain.

Description.—Burhead (fig. 19) is an aquatic, emersed, erect annual that reproduces by seed. The plants are 24 to 48 inches tall and bear many whorls of flowers. The leaves have long petioles; the leaf blades are egg shaped, have heart-shaped bases, and are up to 10 inches long by 5 to 6 inches wide. The fruit, which resembles a bur, is 0.25 to 0.5 inch in diameter. The seeds are about 0.1 inch long, sharply ridged, and short beaked.

Distribution.—Burhead grows in most rice-producing States. It frequently grows in ricefields, shallow irrigation and drainage canals, ditches, potholes, sloughs, and other wet areas. It is most troublesome in areas where rice stands are thin or where cold water enters the ricefield. Burhead germinates under water.

PN-4954

FIGURE 18.—Hardstem bulrush (*Scirpus acutus*).

PN-4955

FIGURE 19.—Burhead (*Echinodorus cordifolius*).

CATTAIL

Typha spp.

Other names.—Flags, tules, and reedmace.

Principal species.—*T. angustifolia* L., *T. domingensis* Pers., *T. glauca* Godr., and *T. latifolia* L. (fig. 20).

Description.—Cattails are perennials that reproduce by rootstocks and by minute airborne seeds that germinate readily in mud and occasionally in shallow, clear water. The plants, which have an extensive rhizome system, are erect and have long, narrow leaves. The flowers are in a long and very dense cylindrical spike terminating the stem. The plants are 4 to 8 feet tall and usually grow in colonies. The seeds may remain viable for more than 5 years in the soil.

Distribution.—Cattails grow in all rice-producing States, but all species are not found in every State. They grow in shallow water in irrigation and drainage ditches and may grow in rice where drainage is inadequate. They compete with rice and impede the flow of water in irrigation systems.

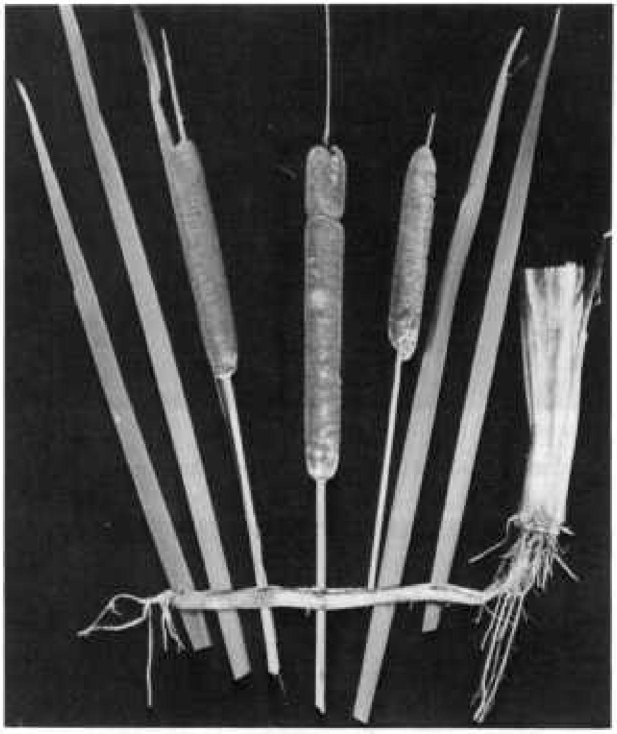
COMMON WATERPLANTAIN

Alisma triviale Pursh

Other names.—Waterplantain and waterlily.

Description.—Common waterplantain (fig. 21), an emersed, erect, aquatic perennial that reproduces by seed and rootstocks, may grow 48 inches tall. The elliptical leaf blades, up to 10 inches long and 6 inches wide, grow on long petioles. The inflorescence is pyramid shaped and branched. The seeds are round, reddish brown, and about 0.1 inch long and may remain viable in the soil for many years.

Distribution.—Common waterplantain is



PN-4956
FIGURE 20.—Cattail (*Typha latifolia*), showing leaf, spike, stem, and root parts.

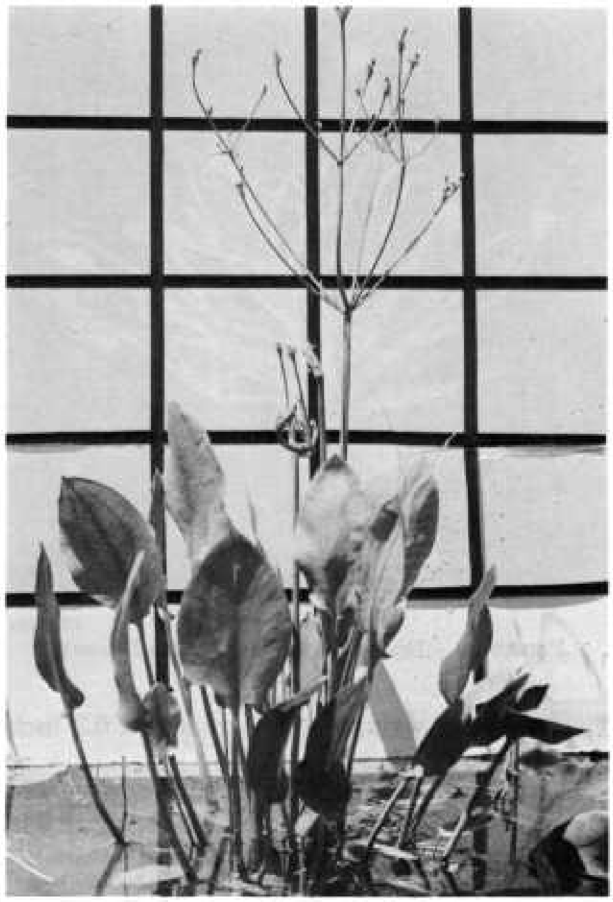
found in rice in California only. It grows in ricefields where stands are thin, on banks and edges of irrigation and drainage canals, and in most wet areas; it often grows abundantly where cold water enters the ricefield. The seeds germinate under water and at a lower temperature than rice.

DAYFLOWER

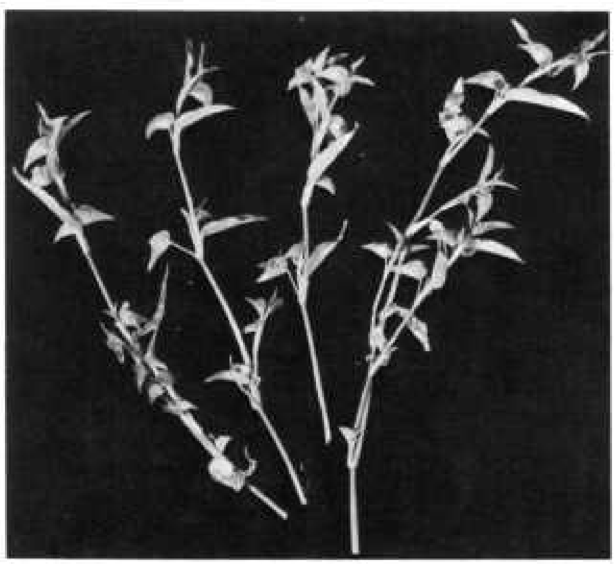
Commelina diffusa Burm. f.

Other names.—Spreading dayflower, wandering-Jew, batwing, and water parsley.

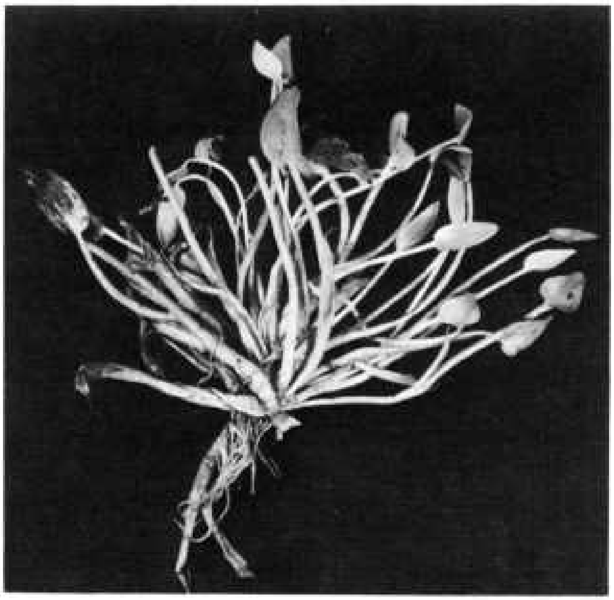
Description.—Spreading dayflower (fig. 22) is an annual that reproduces by seeds. Its succulent stems, 1 to 3 feet long, grow erect in the seedling stage but begin to spread or creep in midsummer or later. Roots may grow from the lower nodes. The alternate, lance-shaped leaves, 2 to 4 inches long and about half as wide, clasp the stem. Irregularly shaped flowers, blue or purplish blue and about 0.5 inch wide, are borne on boat-shaped, leaflike structures about 1 inch long and half as wide.



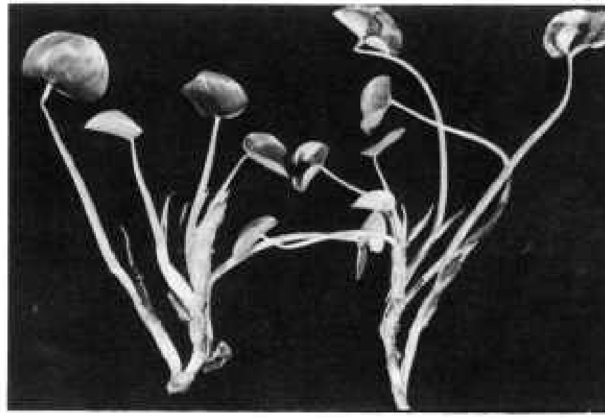
PN-4957
FIGURE 21.—Common waterplantain (*Alisma triviale*).



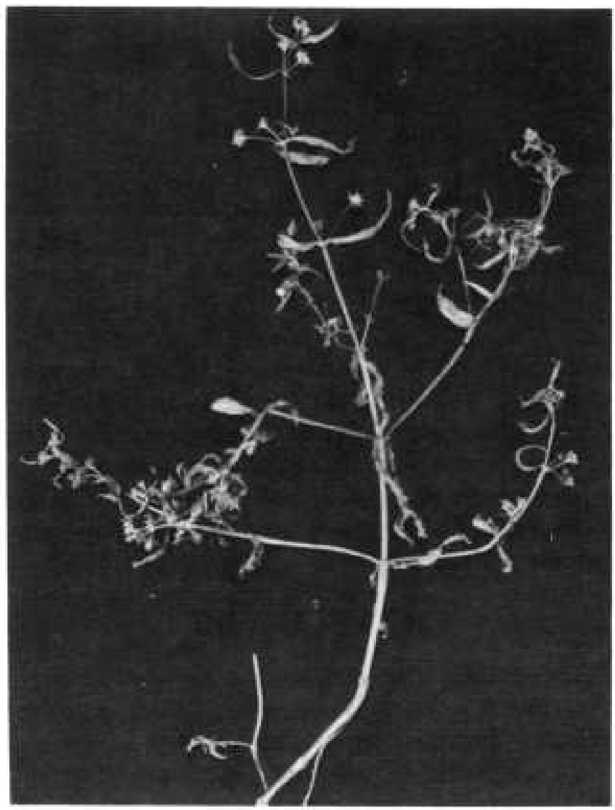
PN-4958
FIGURE 22.—Spreading dayflower (*Commelina diffusa*).



PN-4959
FIGURE 23.—Ducksalad (*Heteranthera limosa*).



PN-4960
FIGURE 24.—Mudplantain (*Heteranthera reniformis*).



PN-4961
FIGURE 25.—Eclipta (*Eclipta alba*).

The seeds are wrinkled and are about 0.2 inch long.

Distribution.—Spreading dayflower grows in the South. It is particularly troublesome in the ratoon rice crop in Louisiana and Texas. It grows profusely in late July or early August, after the first crop has been harvested and when the ratoon crop is watered and fertilized. Spreading dayflower reduces yields, lowers the market value of rough and milled rice because seeds are difficult to remove, interferes with harvesting, and slows drying.

DUCKSALAD

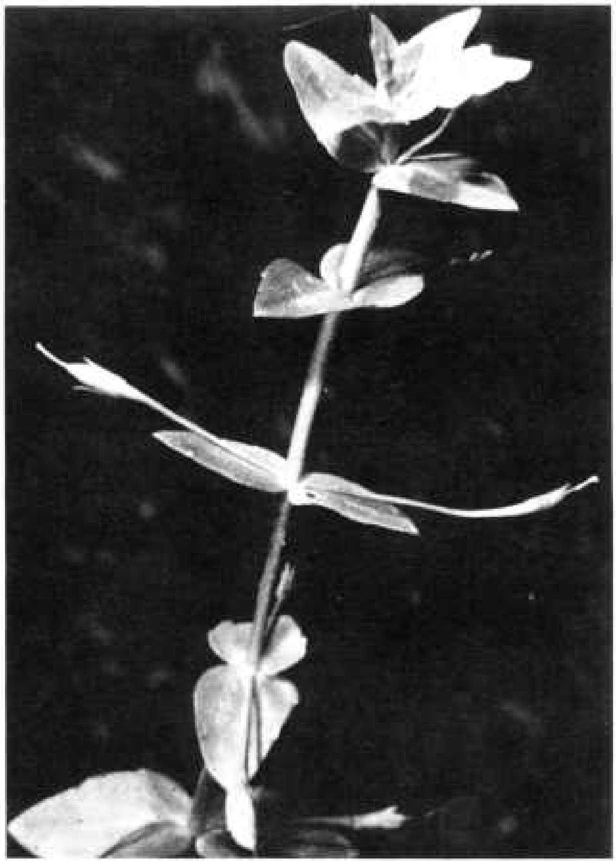
Heteranthera spp.

Other names.—Mudplantain and waterlily.

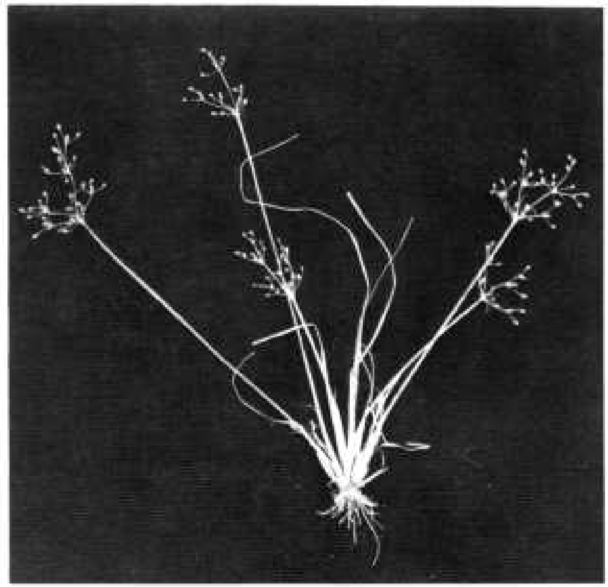
Principal species.—*H. limosa* (Sw.) Willd. (fig. 23) and *H. reniformis* R.&P. (fig. 24).

Description.—Species of ducksalad are aquatic annuals that reproduce by seed. Leaf shape and flower number differentiate *H. limosa* and *H. reniformis*. The leaves of *H. limosa* are oval, narrow, and 0.5 to 5 inches long; the inflorescence has only one flower. In contrast, the leaves of *H. reniformis* are kidney shaped or heart shaped, 1 to 3 inches long, and about as broad; the inflorescence has two or more flowers. Ducksalad seeds which are minute, ridged, and black, are borne copiously in a dehiscent capsule.

Distribution.—Ducksalad is a troublesome weed in all ricegrowing areas. It grows in rice, in shallow water in irrigation and drainage canals, and in ditches, potholes, sloughs, and



PN-4962
FIGURE 26.—False pimpernel (*Lindernia pyxidaria*).



PN-4963
FIGURE 27.—Fimbristylis (*Fimbristylis miliacea*).

other wet areas. It is particularly troublesome in water-seeded rice. The seeds germinate only in saturated or flooded soil in an anaerobic environment. The young plants compete with rice early in the growing season and reduce yields.

ECLIPTA

Eclipta alba (L.) Hassk.

Other names.—Tagoweed and yerba-de-tago.

Description.—Eclipta (fig. 25) is a weakly branched annual that reproduces by seeds. Its fine-haired stems, 8 to 36 inches tall, grow erect; the base, however, may recline, and roots often emerge from the nodes. The leaves, 1 to 4 inches long and slightly toothed along the margins, are lance shaped, sessile, and opposite. Several bell-shaped flower heads are borne on elongated stalks that grow from the leaf axils; they contain many white ray flowers. The seeds are triangular to rectangular and somewhat flattened.

Distribution.—Eclipta grows in the South in ricefields where stands are thin, on levees, and along the banks of irrigation systems. It reduces yields, interferes with harvesting, and slows drying.

FALSE PIMPERNEL

Lindernia spp.

Principal species.—*L. anagallidea* (Michx.) Pennell and *L. pyxidaria* L. (fig. 26).

Description.—False pimpernel is a loosely branched aquatic annual, 4 to 8 inches tall, that reproduces by seed. *L. pyxidaria* is more branched than *L. anagallidea*. The smooth-margined leaves, 0.2 to 0.8 inch long, are elliptical, but broader at the base than at the tip. White or pale lavender flowers, 0.2 to 0.3 inch long, are borne on axillary stalks about twice as long as the leaves. The flowers of *L. pyxidaria* are shorter (usually less than 0.2 inch) than those of *L. anagallidea*. The sepals of *L. pyxidaria* are usually as long as the corolla, but those of *L. anagallidea* are usually shorter. The seed pods, 0.1 to 0.2 inch long, contain many brown or yellow seeds.

Distribution.—False pimpernel grows in the

PN-4964
FIGURE 28.—Gooseweed (*Sphenoclea zeylanica*).

PN-4965
FIGURE 29.—Hemp sesbania (*Sesbania exaltata*).

South, usually with other aquatic weeds such as ducksalad, redstem, and waterhyssop. It is most troublesome where stands of rice are thin or where rice is seeded in water. It grows in rice, shallow ditches, canals, and most wet areas. It competes with rice during the early growing season and may reduce tillering and yield.

FIMBRISTYLIS

Fimbristylis spp.

Other name.—Hoorahgrass.

Principal species.—*F. autumnalis* (L.) R.&S. and *F. miliacea* (L.) Vahl (fig. 27).

Description.—Species of fimbristylis are turflike annuals that reproduce by seed. The culms are slender, erect to decumbent, leafy at the base, 12 to 18 inches tall at maturity, and weak; they lodge easily. The leaf blades are narrow and short. The inflorescence is open and has several small foliagelike bracts of variable length at its base.

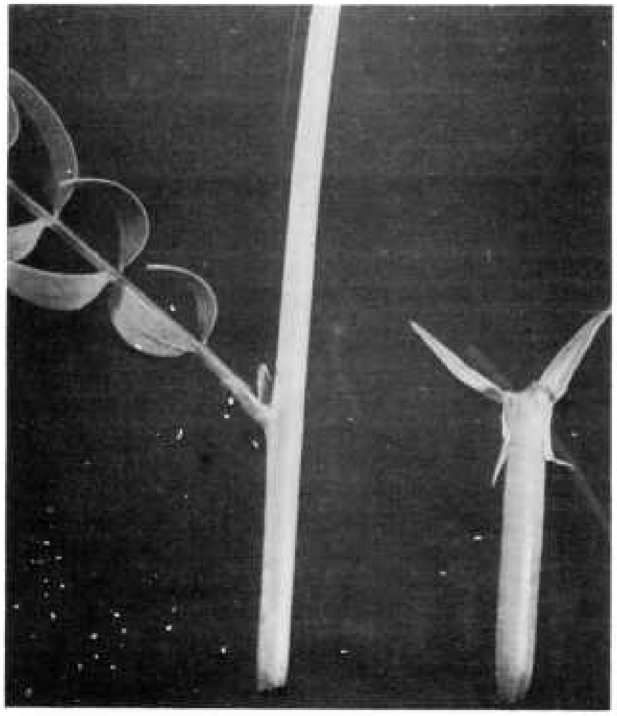
Distribution.—Fimbristylis is troublesome only in the South. It grows in rice, on levees, along canals, and in most wet areas. It competes with rice in thin stands and reduces yields.

GOOSEWEED

Sphenoclea zeylanica Gaertn.

Other name.—Hollowstem.

Description.—Gooseweed (fig. 28) is an aquatic annual that reproduces by seed. Its stems are erect, smooth, hollow, and 1 to 5 feet tall. The leaves are elliptical to linear, smooth margined, 1 to 4 inches long, and light green (paler beneath than above). Flowers are borne on a continuous dense spike and are white or greenish. The bucket-shaped seed pods, about 0.2 inch in diameter, contain many small red or brown seeds.



PN-4966
FIGURE 30.—The needlelike stipules of hemp sesbania (*left*) distinguish it from northern jointvetch (*right*).

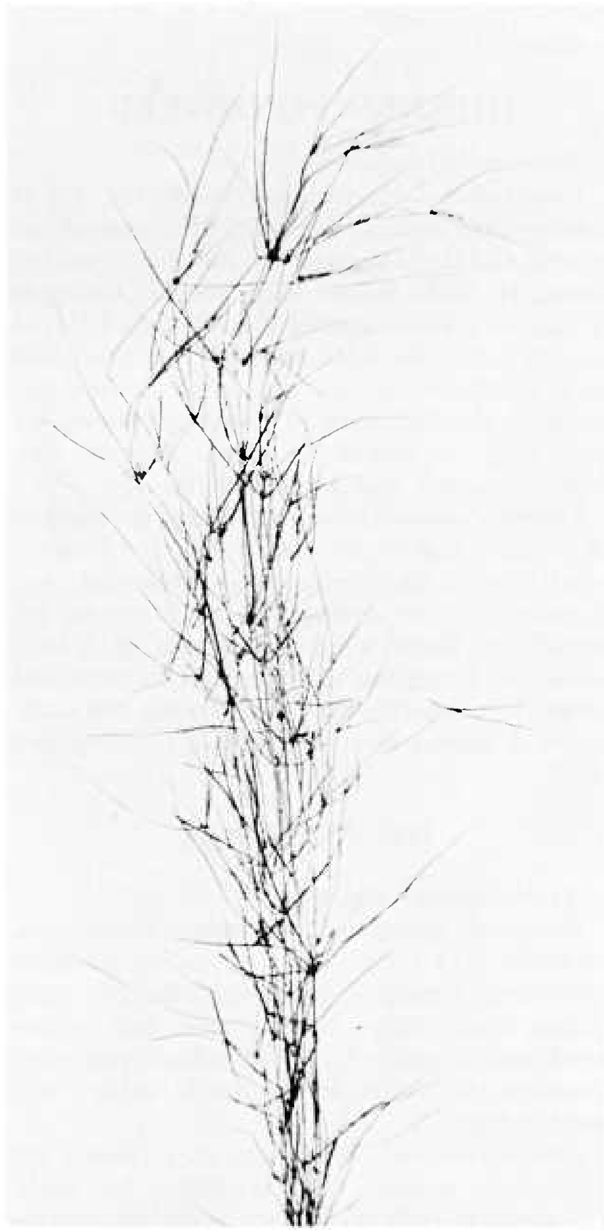
Distribution.—Gooseweed grows in the South in rice where stands are thin, in irrigation and drainage canals, in ditches, along levees, and in most wet areas. It competes with rice, interferes with harvest, and prolongs drying when it is green and succulent.

HEMP SESBANIA

Sesbania exaltata (Raf.) Cory

Other names.—Coffeebean, coffeeweed, tall-indigo, sennabean, and sesbania.

Description.—Hemp sesbania (fig. 29) is a tall, erect, smooth, leguminous annual that reproduces by seed. It may grow 12 to 15 feet tall. The leaves are compound, with 12 to 25 pairs of leaflets. The flowers are yellow and usually mottled with purple. The narrow, compressed pods, 6 to 12 inches long, contain numerous small, oblong seeds separated by transverse partitions. The seeds may be viable in the soil for many years. Young plants of hemp sesbania resemble those of northern jointvetch, but they may be identified by the small, narrow bract or stipule, the smooth stem (fig. 30), and the simple leaf that emerges just after the cotyledons.



PN-4967
FIGURE 31.—Horned pondweed (*Zannichellia palustris*).

Distribution.—Hemp sesbania is a problem weed in the South in uncultivated fields, waste areas, row crops, and rice, on levees, and along canals and ditches. It does not grow in California. It competes with rice, interferes with harvest, and reduces the value of rough and milled rice because its seeds are difficult to remove.

HORNED PONDWEED

Zannichellia palustris L.

Description.—Horned pondweed (fig. 31) is a submersed aquatic perennial that reproduces by seed and slender rhizomes. Slender, branched stems, 10 to 30 inches long, root at the node or may be free swimming. Leaves 1 to 4 inches long by 0.02 inch wide emerge from the nodes in a whorl. Numerous unisexual flowers are borne in the leaf axils. The achenial seed, 0.1 inch long, is sessile or short stalked, flat, slightly curved, and beaked at the tip.

Distribution.—Horned pondweed is found in all ricegrowing States, but it is a troublesome weed only in California in water-seeded rice. It grows in rice during the early season, especially in fields with deep floods of 6 to 8 inches, in irrigation systems, and in most wet areas. It competes with rice during the early growing season and may reduce tillering and yield.

JOINTVETCH

Aeschynomene spp.

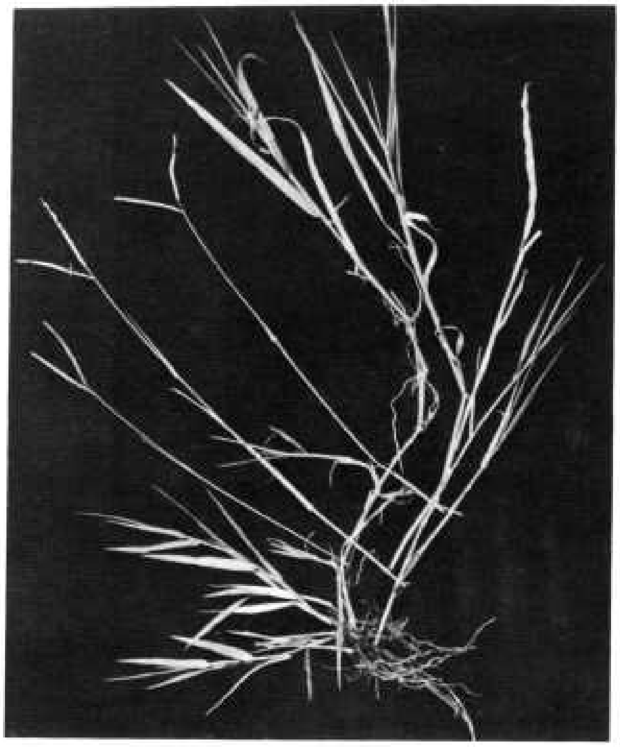
Principal species and common names.—*A. virginica* (L.) B.S.P. (fig. 32), called northern jointvetch, sensitive jointvetch, indigo, curly indigo, short indigo, bashfulweed, and coffeeweed; and *A. indica* L., called Indian jointvetch, sensitive jointvetch, indigo, curly indigo, and short indigo.

Description.—*A. indica* and *A. virginica* are leguminous annuals that reproduce by seeds. The stems of both species are branched, sparsely bristled at the base but abundantly bristled near the apex, and 2 to 5 feet tall. The compound leaves have short petioles, and 25 to 55 linear, oblong leaflets that fold at night or when touched. The leaves of *A. indica* taper more at the tip and are a paler green than those of *A. virginica*. The stipules are large and deciduous, especially those below the tip of the stem. The inflorescence is axillary, often leafy, and contains one to six yellow, red-veined flowers. The pods, 1 to 3 inches long, are segmented into 4 to 10 nearly square joints that separate easily at maturity. The pods of *A. indica* are smaller than those of *A. virginica*. The seeds are kidney shaped and remain viable for many years in the soil. The seeds of *A. indica* are smaller than those of *A. virginica*. The young plants resemble hemp sesbania and may be identified by their large stipules (fig. 30) and bristly stems near the shoot apex.

PN-4968

FIGURE 32.—Northern jointvetch (*Aeschynomene virginica*).

Distribution.—*A. indica* and *A. virginica* are troublesome weeds in the South. *A. virginica* is more common in ricefields than *A. indica*; the estimated distribution ratio in ricefields for the two species is 19 to 1. Jointvetch grows in rice, on levees, in uncultivated fields and waste areas, and along canal and ditch banks. Both species compete with rice, interfere with harvest, and reduce the value of rough and milled rice because their seeds are difficult to remove.



PN-4969
FIGURE 33.—Knotgrass (*Paspalum distichum*).

KNOTGRASS

Paspalum spp.

Principal species and common names.—*P. distichum* L. (fig. 33), called knotgrass, water bermudagrass, jointgrass, and lakegrass; *P. lividum* Trin., known commonly as longtom, doggrass, and watergrass; and *P. acuminatum* Raddi., called brookpaspalum, watergrass, and crawlinggrass.

Description.—The principal species are perennials that reproduce by seed and creeping runners. *P. distichum* has long stolons, often 25 feet long; relatively short, 1- to 3-inch leaf blades; and two ascending 1- to 2-inch racemes or seed heads, often incurved. *P. lividum* is a smooth, creeping grass with 20- to 40-inch culms, 6- to 10-inch purple-tipped leaf blades, and usually four to seven dark-purple racemes on the seedstalk. *P. acuminatum* resembles *P. lividum* except that it has shorter and wider leaf blades with very light-colored midribs, and its seed heads bear three to five (usually three) erect or descending racemes 2 to 3 inches long.

PN-4970
FIGURE 34.—Mexicanweed (*Caperonia castaneaefolia*).

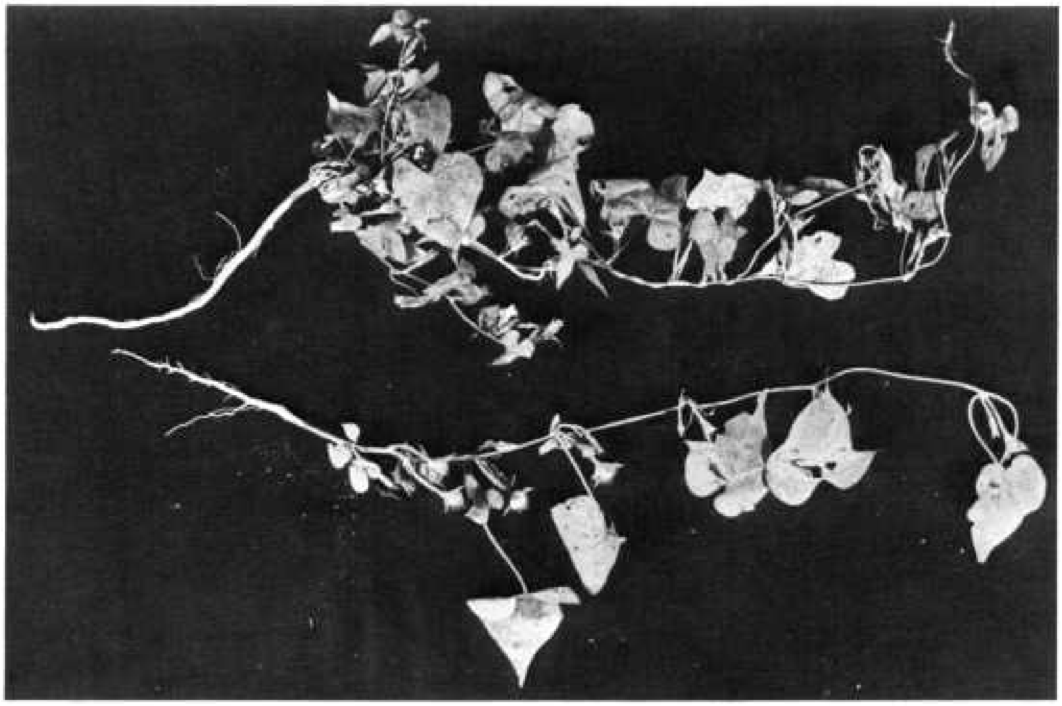
Distribution.—Knotgrass grows in all rice-producing areas, but longtom and brookpaspalum grow only in southern Louisiana and Texas. They are usually most troublesome in young rice and in irrigation and drainage canals, where they impede the movement of water. These weeds compete with rice and reduce yields.

MEXICANWEED

Caperonia castaneaefolia (L.) St. Hil.

Other names.—Birdeye and Texas-weed.

Description.—Mexicanweed (fig. 34) is a tough, fibrous-rooted annual that reproduces by seed. The leaves are alternate, about 2 inches wide, 3 to 5 inches long, prominently veined,



PN-4971

FIGURE 35.—Small white morningglory (*Ipomoea obscura*).

coarsely toothed on the margin, and petioled. The stem is rough, hairy, and 2 to 3 feet tall. Mexicanweed has small white flowers and a burlike fruit. The seeds are spherical, gray with distinctive light-colored markings, and about 0.12 inch in diameter.

Distribution.—Mexicanweed is troublesome in Louisiana and Texas. It grows in rice, on levees, and in most wet areas. It competes with rice, interferes with harvesting, and lowers the value of rough and milled rice because its seeds are difficult to remove.

MORNINGGLORY

Ipomoea spp.

Principal species and common names.—*I. obscura* Hassk., called small white morningglory (fig. 35); *I. hederacea* (L.) Jacq., called ivyleaf morningglory; *I. purpurea* (L.) Roth, called tall morningglory; and *I. wrightii* Gray, called willowleaf morningglory.

Description.—The species of morningglory are twining annuals that reproduce by seed. The stems are glabrous to pubescent and 3 to 15 feet long. The leaves of both *I. obscura* and *I. purpurea* are heart shaped, but those of *I. obscura* have purple margins; those of *I. hederacea* have three deeply cut lobes with rounded sinuses; and those of *I. wrightii* are divided into three to seven palmlike leaflets. The flowers of *I. obscura, I. hederacea,* and *I. purpurea* are solitary or in clusters on stalks arising from the leaf axils, funnel shaped, and white, purple, or pale blue; those of *I. wrightii* are borne on long axillary stalks terminating with one to several flowers and are orange or red. The corollas of *I. hederacea* and *I. purpurea* are about 2 inches long; those of *I. obscura* and *I. wrightii* are about 1 inch long. Morningglory seeds are about 0.1 to 0.25 inch long, are dark brown or black, and have one round and two flat sides.

Distribution.—Morningglories are troublesome in ricefields in the South, where they grow on levees and on banks of irrigation and drainage canals. They do not grow between levees when water is managed well. They interfere with harvest and lower the value of rough and milled rice because the seeds are difficult to remove. They reduce grain yields of rice on levees.

NAIAD

Najas spp.

Principal species.—*N. flexilis* (Willd.) Rostk. & Schmidt, called slender naiad; and *N. guadalupensis* (Spreng.) Magnus, called southern naiad (fig. 36).

Description.—Naiads are rooted, submersed aquatic annuals that reproduce by seed and vegetatively. The stems, 10 to 25 inches long, are slender and branched. The narrow (0.01 to 0.1 inch wide) leaves, with minute spines along the margins, are 0.5 to 1.5 inches long, opposite or crowded into whorls of three, and tapered from the base to the tip. Small axillary flowers emerge from the sheath at the base of the leaf. The brown or straw-colored seeds, covered by a thin pericarp, are about 0.1 inch long and are marked with numerous lengthwise rows of minute spaces.

Distribution.—Naiads grow in all ricegrowing States, but are troublesome weeds only in California in water-seeded rice. They grow in rice early in the season, especially in fields with deep water, in irrigation systems, and in flooded areas. They compete with rice during the early growing season and may reduce the number of tillers and thus yield.

PANICUM GRASSES

Panicum spp.

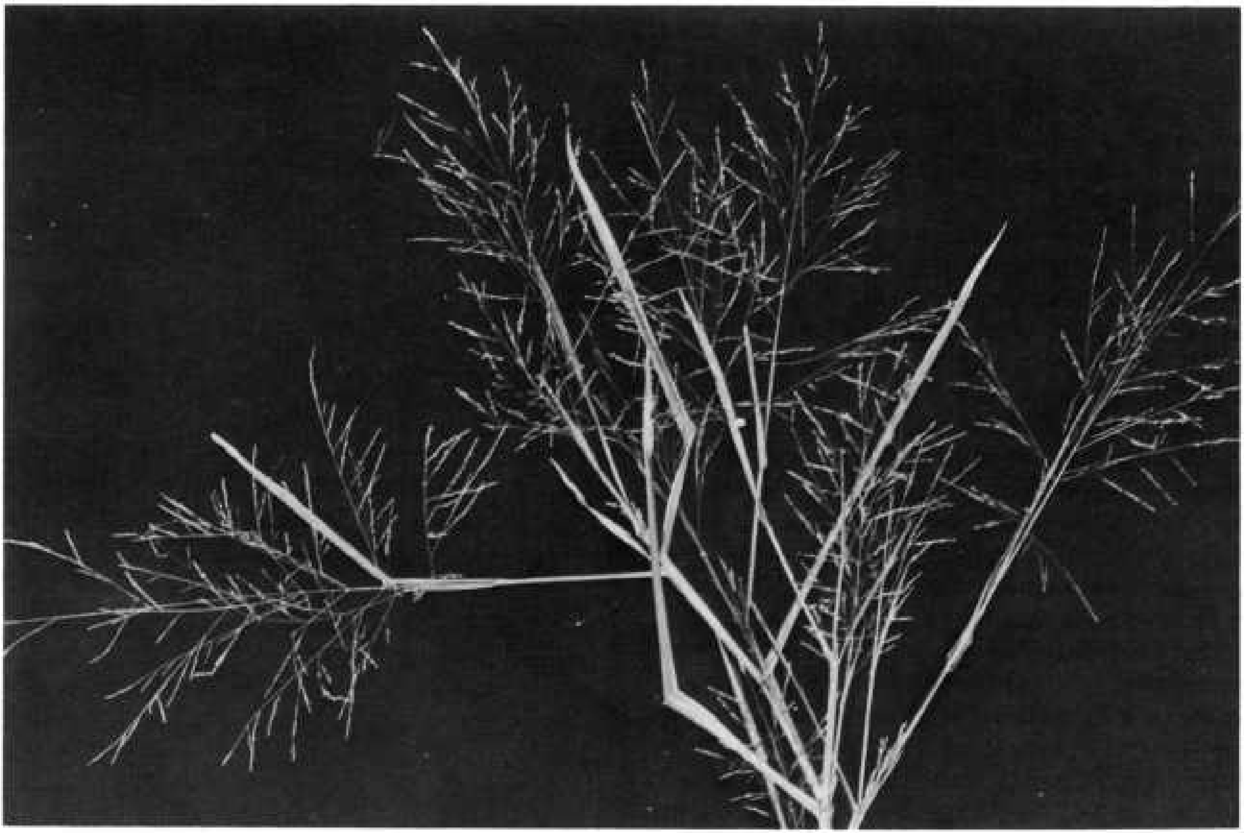
Principal species and common names.—*P. dichotomiflorum* Michx., called fall panicum or spreading panicum (fig. 37); *P. capillare* L., called witchgrass, ticklegrass, or tumbleweed-grass; *P. texanum* Buckl., called Texas panicum, Texas millet, or Colorado grass; and *P. purpurascens* Raddi, called paragrass.

Description.—*P. dichotomiflorum*, *P. capillare*, and *P. texanum* are annuals that reproduce by seeds; *P. purpurascens* is a robust, aquatic perennial that reproduces by seeds and stolons. *P. dichotomiflorum*, *P. capillare*, and *P. texanum* are branched at the base; their stems are erect and usually 15 to 60 inches tall, but robust plants of *P. dichotomiflorum* and *P. texanum* may be 6 to 10 feet tall. The leaves, 4 to 20 inches long by 0.2 to 0.8 inch wide, vary in pubescence from soft hairs in *P. dichotomiflorum* and *P. texanum* to stiff hairs

PN-4972

FIGURE 36.—Southern naiad (*Najas guadalupensis*).

in *P. capillare*. The panicles of *P. capillare* and *P. dichotomiflorum*, 4 to 16 inches long, are loosely spreading and may be terminal or axillary, whereas the panicles of *P. texanum* are somewhat shorter, 3 to 8 inches long, and more compressed. *P. purpurascens* stems, 6 to 15 feet long, recline on the ground and root at the basal nodes; its leaves, 4 to 12 inches long by 0.4 to 0.6 inch wide, are flat and



PN-4973

FIGURE 37.—Fall panicum (*Panicum dichotomiflorum*).

smooth; and its panicles, 5 to 8 inches long, are raceme shaped. The spikelets of all four species are about 0.1 inch long.

Distribution.—*P. capillare* and *P. dichotomiflorum* are troublesome in most ricegrowing areas, but *P. texanum* and *P. purpurascens* grow more abundantly in Louisiana and Texas. Panicum grasses mature in late summer or early fall and grow in rice, in and along irrigation canals, and on levees. They reduce yields by competing with rice late in the growing season and interfere with harvesting; some species impede the flow of water in irrigation systems.

PONDWEED

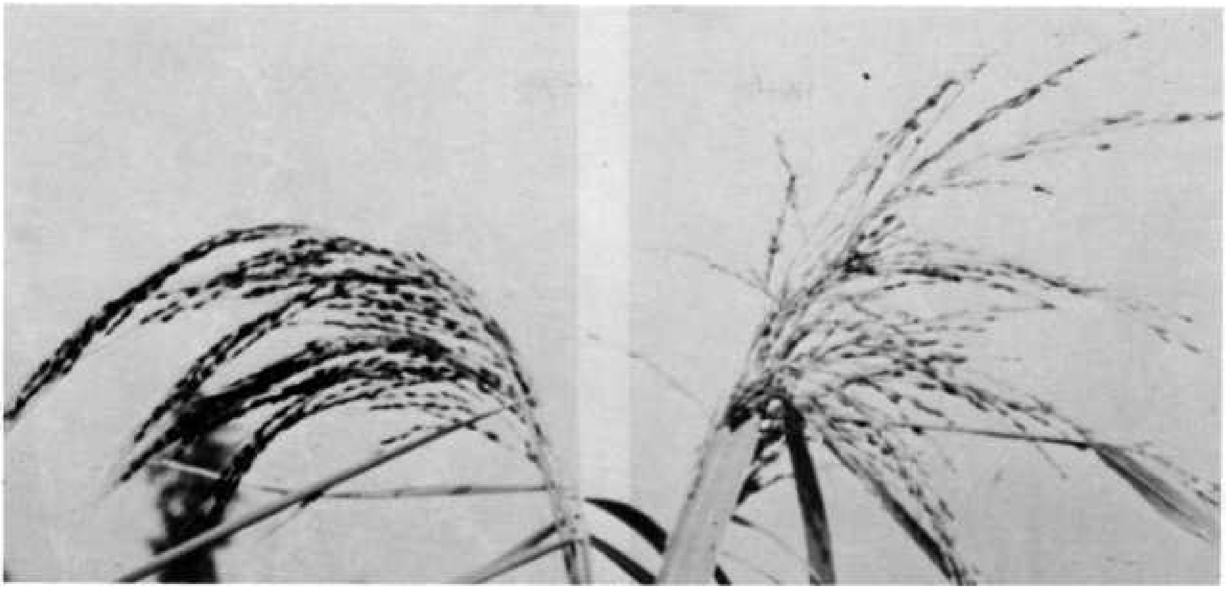
Potamogeton spp.

Principal species.—*P. nodosus* Poir. (fig. 38), called American pondweed, and other species.

Description.—The species of pondweed are

PN-4974

FIGURE 38.—American pondweed (*Potamogeton nodosus*) leaves with distinct parallel veins.



PN-4975

FIGURE 39.—Red rice (*Oryza sativa*) panicles. *Left*, grains have purple or black hulls. *Right*, grains have straw-colored hulls.

aquatic perennials that reproduce by underground winter buds or tubers and also by seed. They have simple or slightly branched stems. The leaves are usually alternate, but the upper leaves may be opposite; the submersed and floating leaves on the same plant are often very different in appearance. Leaf structure varies among species from grasslike to broadleaf with many distinct veins. The flowers in elongated spikes are borne on axillary stalks that vary in length. Whorls of egg-shaped, beaked seed, called achenes, develop in the spikes.

Distribution.—Species of pondweed grow in all rice-producing States. They usually grow in irrigation canals, ditches, and reservoirs, but may be a problem in rice when stands are thin or when rice is grown on land previously used as a reservoir for storage of irrigation water or fish production. Pondweeds compete with rice to lower yields, interfere with harvesting, slow drying, and impede the flow of water in irrigation systems.

RED RICE

Oryza sativa L.

Other names.—Vermillion red rice, Italian red rice, and common red rice (fig. 39).

Principal types.—The many types include those with short, medium, or long grains; those with straw-colored, red, or black hulls; and those with short or long awns on the spikelet.

Description.—Red rice is an annual that reproduces by seed. The plants, which tiller profusely, are difficult to distinguish from white rice plants until they are large; then their brushier growth is discernible. The taller plants shade the crop and often mature and lodge before commercial rice. The leaves have short, stiff hairs on their upper and lower surfaces; the panicles are loose and open and droop slightly. The grain shatters easily when ripe. Seeds buried in the soil remain viable for several years.

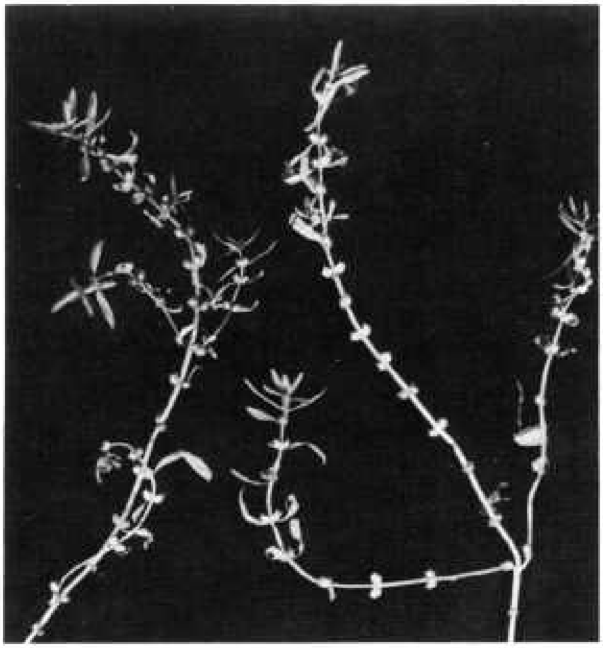
Distribution.—Red rice is a problem weed in all rice-producing States, where it grows in rice, in irrigation and drainage canals, on levees, and in most wet areas. It reduces yields and lowers the market value of rough and milled rice because the seeds are difficult to remove.

REDSTEM

Ammannia spp.

Principal species and common names.—*A. auriculata* Willd., called redstem; *A. coccinea*

PN-4976
FIGURE 40.—Purple ammannia (*Ammannia coccinea*).



PN-4977
FIGURE 41.—Pink ammannia (*Ammannia teres*).

Rothb., called purple ammannia or redstem (fig. 40); and *A. teres* Raf., called pink ammannia, redstem, or toothcup (fig. 41).

Description.—All species of redstem are aquatic annuals that reproduce by seed. The stems are erect and 8 to 40 inches tall; those of *A. auriculata* and *A. coccinea* are often freely branched, but those of *A. teres* are sparsely branched. The leaves are narrow and 0.5 inch wide by 1 to 4 inches long; the leaves of *A. auriculata* and *A. coccinea* are clasping at the base, but those of *A. teres* taper. The flowers are borne in the axils of the leaves; the flowers of *A. coccinea* and *A. teres* are attached directly to the stem, but those of *A. auriculata* are on stalks. Small red or brown seeds are produced in spherical capsules 0.1 to 0.2 inch in diameter. The leaves and stems turn red at maturity.

Distribution.—Redstem is a problem weed in all rice-producing States, where it grows in rice, along levees, ditches, and canals, and in most wet areas. It grows especially well where rice stands are thin. It reduces yields, interferes with harvesting, lowers the value of rough rice, and increases the cost of drying when immature pods are present because the seed pods are difficult to remove.

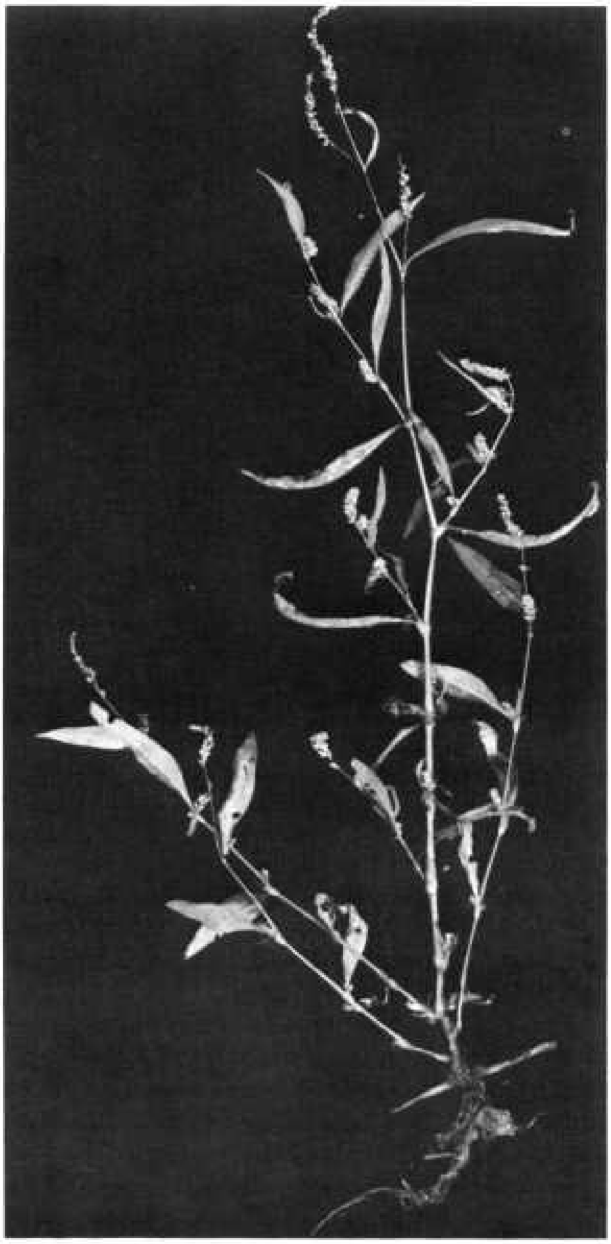
SMARTWEED

Polygonum spp.

Other names.—Knotweed and pepperweed (fig. 42).

Description.—Numerous species infest rice. Some are annual herbs and others are perennial; some species grow erect and others are prostrate. The plants are usually 2 to 6 feet tall, with thick-jointed stems and alternate, linear, short-petioled leaves. The flowers are in axillary clusters or in nodding spikes or panicles. The seeds are small, three-angled achenes with dark-brown or black, hard coats.

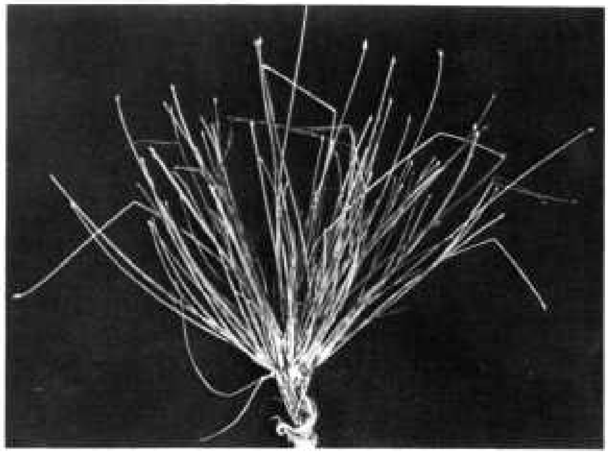
Distribution.—Smartweeds grow in ricefields where cultivation and drainage are inade-



PN-4978

FIGURE 42.—Smartweed (*Polygonum* sp.).

quate, in drainage and irrigation ditches, potholes, and sloughs, on levees, and in most wet areas. Some smartweeds are true aquatics and grow in shallow water; others are upland weeds. They reduce rice yields, interfere with harvesting and drying, and lower the value of rough and milled rice because their seeds are difficult to remove.



PN-4979

FIGURE 43.—Blunt spikerush (*Eleocharis obtusa*).

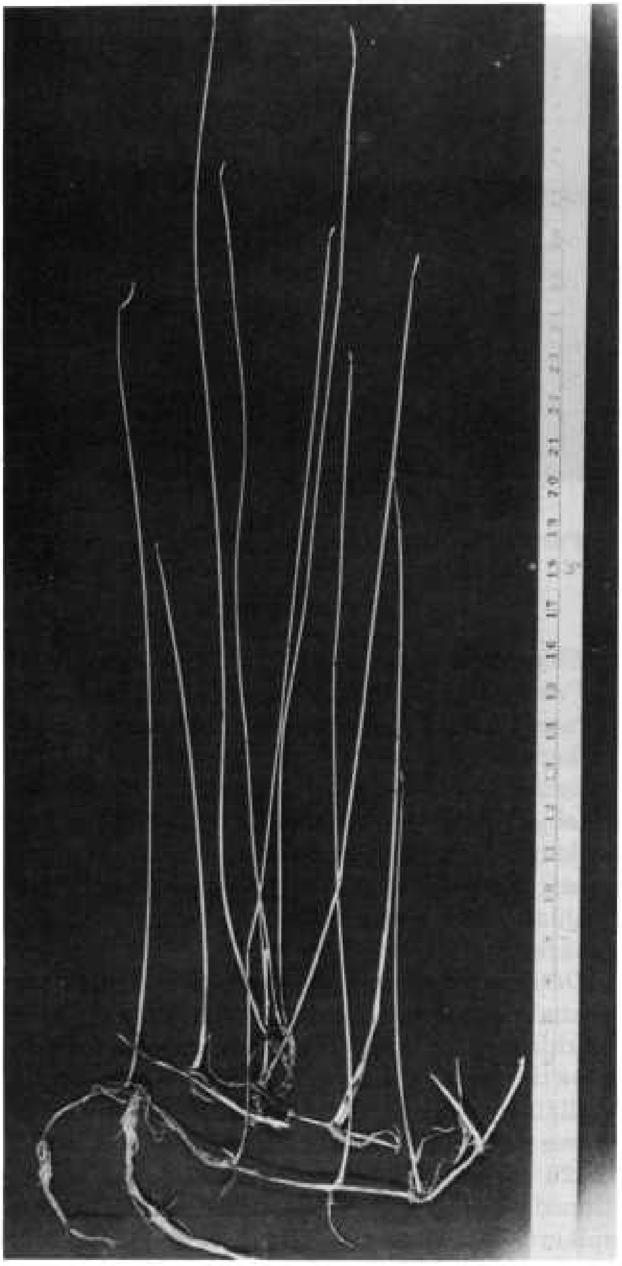
SPIKERUSH

Eleocharis spp.

Principal species and common names.—*E. obtusa* (Willd.) Schultes (annual), called blunt spikerush (fig. 43); *E. parvula* (R.&S.) Link (annual), called dwarf spikerush; *E. macrostachya* Britt. (perennial), called creeping spikerush (fig. 44), common spikerush, or wiregrass; *E. quadrangulata* (Michx.) R.&S. (perennial), called squarestem spikerush or foursquare; and others.

Description.—The species of *Eleocharis* are annuals or perennials that reproduce by seed or rhizomes or both. The plants are turflike in growth and have simple round, erect or slightly reclining culms terminating in seed heads. The leaves are bladeless sheaths. *E. obtusa* is 12 to 20 inches tall at maturity and has blunt-tipped sheaths. *E. parvula* is one of the smallest spikerushes; it grows only 1 to 4 inches tall. *E. macrostachya* grows about 1.5 to 3 feet tall and creeps. *E. quadrangulata* grows to a height of 3 feet and has stout, thick, sharply square culms.

Distribution.—Spikerushes grow in all rice-producing States. *E. macrostachya* is especially troublesome in California. Spikerushes grow in rice, on levees, in shallow ditches, and on poorly drained soil. *E. obtusa* and *E. parvula* are especially troublesome in water-seeded rice. They compete with rice in the early growing season and may reduce yields greatly.



PN-4980

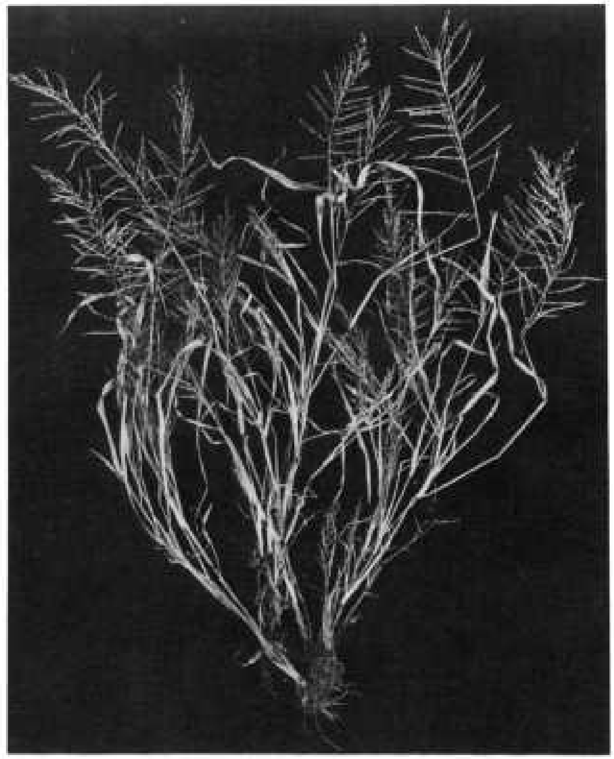
FIGURE 44.—Creeping spikerush (*Eleocharis macrostachya*).

SPRANGLETOP

Leptochloa spp.

Other names.—Raygrass and feathergrass.

Principal species and common names.—*L. panicoides* (Presl) Hitchc., called tighthead sprangletop, Amazon sprangletop, and Christmastreegrass (fig. 45); *L. fascicularis* (Lam.) Gray, called bearded sprangletop (fig. 46); *L. filiformis* (Lam.) Beauv., called red sprangletop; *L. nealleyi* Vasey, called Nealley sprangletop; and *L. uninervia* (Presl) Hitchc. & Chase, called Mexican sprangletop.



PN-4981

FIGURE 45.—Tighthead sprangletop (*Leptochloa panicoides*).

Description.—The species of sprangletop are annuals that reproduce from very small seeds that are seldom found in rough rice. The plants grow 2 to 3 feet tall, tiller heavily, and have fine stems that terminate in panicles.

Distribution.—Except for *L. panicoides*, which does not grow in California, sprangletop is found in all rice-producing States. It grows in shallow water along canals, in rice, and on levees. It is particularly troublesome where stands of rice are thin. It grows especially well in the heavy clay soils of the Mississippi River bottom lands.

UMBRELLAPLANT

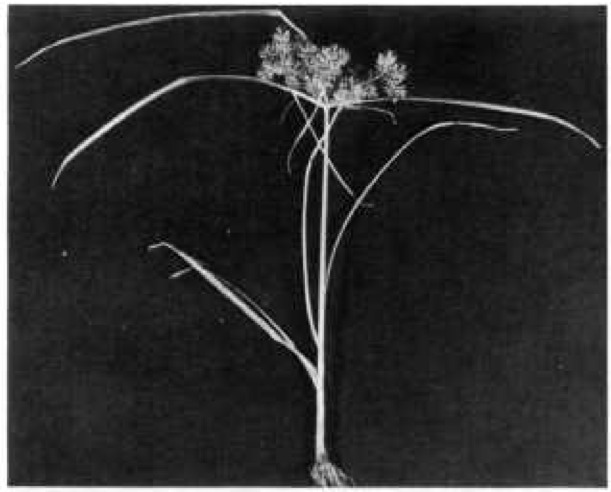
Cyperus spp.

Other names.—Nutgrass, nutsedge, and umbrellasedge.

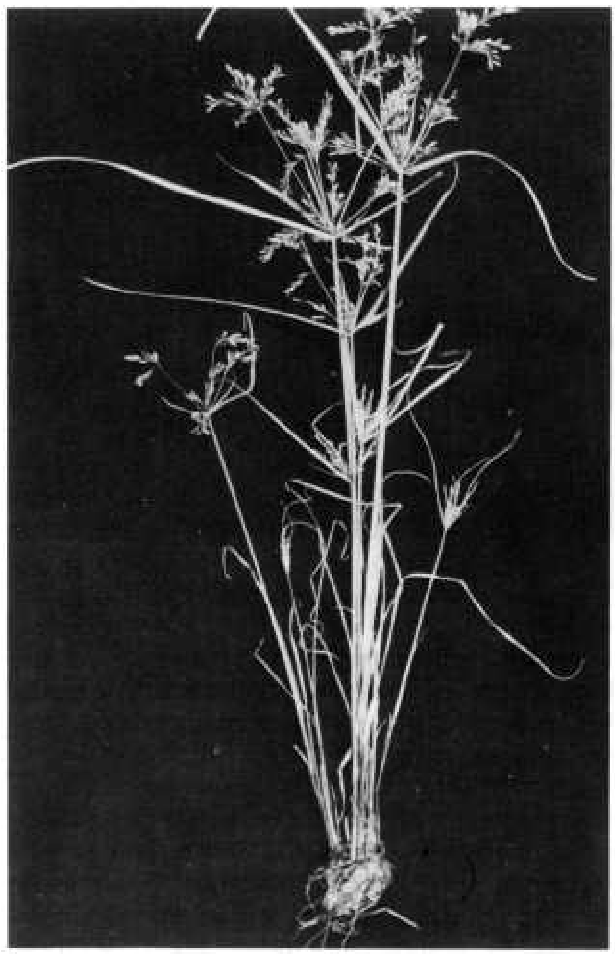
PN-4982
FIGURE 46.—Bearded sprangletop (*Leptochloa fascicularis*).

Principal species and common names.—*C. erythrorhizos* Muhl. (annual), called redroot flatsedge (fig. 47); *C. articulatus* L. (perennial), called jointed flatsedge, jointed sedge, and onions; *C. iria* L. (annual), called rice flatsedge (fig. 48); *C. difformis* L. (annual), called smallflower umbrellaplant; *C. strigosus* L. (perennial), called false nutsedge and straw-colored sedge (fig. 49); and *C. esculentus* L. (perennial), called yellow nutsedge.

Description.—The species of *Cyperus* are annuals and perennials that reproduce by seed or tubers or both. The general appearance of plants within each species varies greatly. Most species have a triangular flower stalk bearing



PN-4983
FIGURE 47.—Redroot flatsedge (*Cyperus erythrorhizos*).

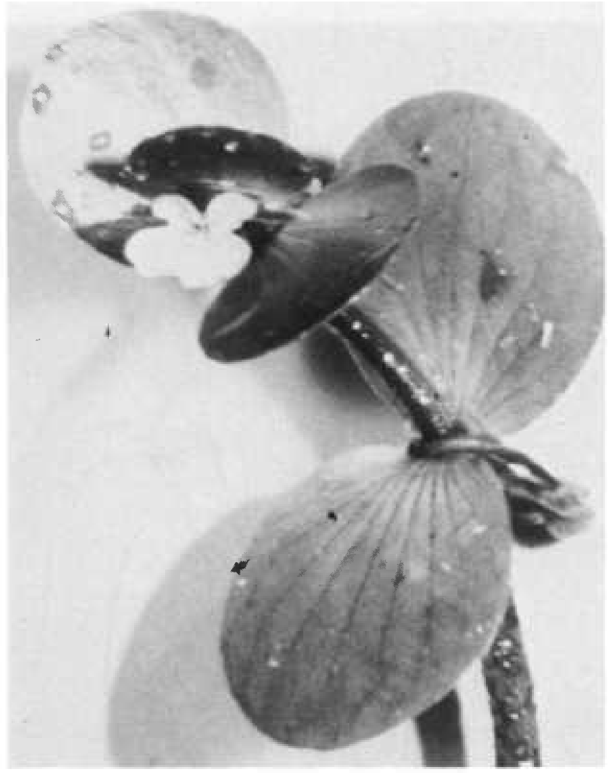


PN-4984
FIGURE 48.—Rice flatsedge (*Cyperus iria*).

PN-4985
FIGURE 49.—False nutsedge (*Cyperus strigosus*).

a headlike or branched inflorescence. At the base of the inflorescence there are foliagelike bracts that vary in size and number. Most umbrellaplants grow 1 to 2 feet tall.

Distribution.—Umbrellaplants grow in all rice-producing States. *C. erythrorhizos* and *C. iria* are troublesome in the South, and *C. difformis* is prevalent in California. They grow in rice, in and along irrigation and drainage canals, in sloughs and other poorly drained areas, and on levees. The perennials, except *C. esculentus*, usually are prevalent in poorly drained areas, such as idle ricefields, but may infest ricefields when seedbed preparation is inadequate. The annual umbrellaplants are more troublesome in the rice crop than the perennials. *C. erythrorhizos*, *C. iria*, and *C. difformis* are especially troublesome where rice stands are thin; they ordinarily appear late in the season, after the land has been submerged for some time. Umbrellaplants reduce yields and interfere with harvesting.



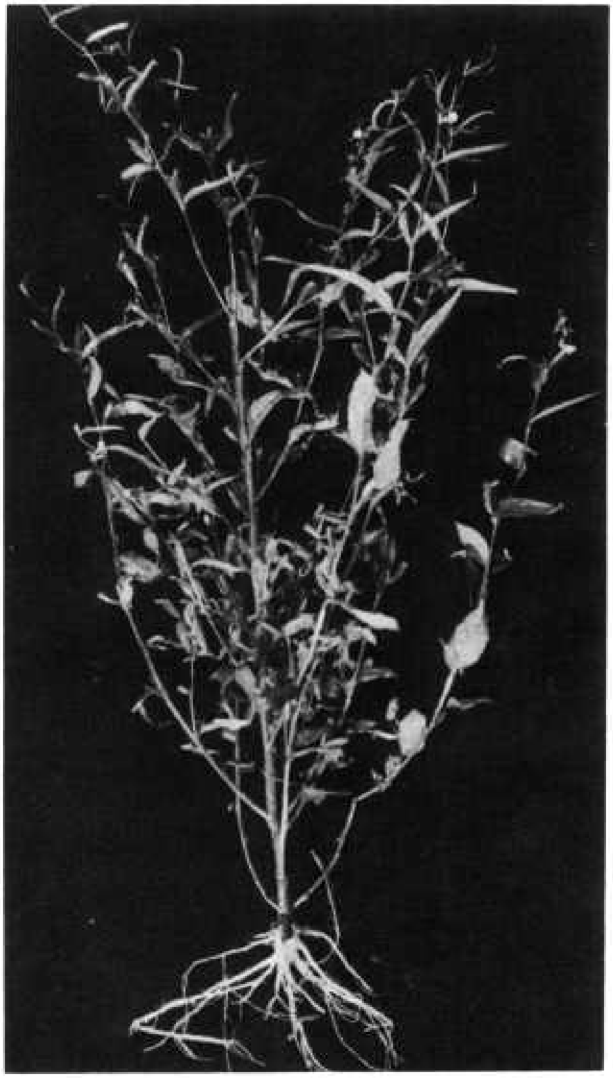
PN-4986
FIGURE 50.—Waterhyssop (*Bacopa rotundifolia*).

WATERHYSSOP

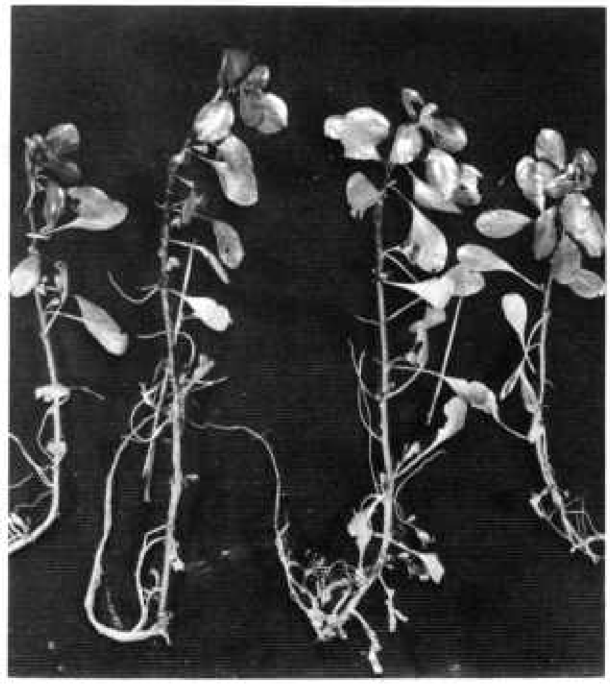
Bacopa rotundifolia (Michx.) Wettst.

Description.—Waterhyssop (fig. 50) is an aquatic annual that reproduces by seed. The stems, 8 to 24 inches long, are submerged with the tips floating; they are pubescent when young. The leaves are thin, round, clasping at the base, and palmately veined. The flowers, two to four at each node, are white with a yellow throat, pediceled, and axillary.

Distribution.—Waterhyssop grows in all rice-producing States. It is usually found with other



PN-4987
FIGURE 51.—Winged waterprimrose (*Jussiaea decurrens*).



PN-4988
FIGURE 52.—Creeping waterprimrose (*Jussiaea repens* var. *glabrescens*).

aquatic weeds, such as ducksalad, and it is most troublesome where stands of rice are thin or where rice is seeded in water. It grows in rice, shallow ditches and canals, and most wet areas. It competes with rice during the early growing season and may reduce tillering and yield.

WATERPRIMROSE

Jussiaea spp.

Other name.—Primrose-willow.

Principal species and common names.—*J. decurrens* (Walt.) DC. (fig. 51), called winged waterprimrose; and *J. repens* L. var. *glabrescens* Ktze. (fig. 52), called creeping waterprimrose.

Description.—*J. decurrens* is an aquatic annual that reproduces by seed. The stems are erect, 3 to 6 feet tall, smooth and square; the leaves are narrow, linear, and sessiled; and the capsules are slender, square, and 0.5 to 1 inch long. *J. repens* var. *glabrescens* is an aquatic perennial that reproduces by seed, stems, and rootstocks. The stems are smooth, prostrate or floating, and ascending at the tips; the leaves are smooth, oblong, 1 to 4 inches long, and petioled; the capsules are almost cylindrical and 1 to 2 inches long. Roots form at the nodes.

Distribution.—Waterprimroses grow mainly in the South in irrigation and drainage canals, ditches, and most wet areas. *J. repens* var. *glabrescens* grows in dense beds in ponds and ditches. Waterprimroses are not generally troublesome in rice, except where stands are thin. They compete with rice, interfere with harvesting, slow drying, lower the value of rough and milled rice, and impede the flow of water in canals and ditches.

SELECTED REFERENCES

(1) Adair, C. R., and Engler, Kyle. 1955. The irrigation and culture of rice. U.S. Dep. Agric. Yearb. Agric. 1955: 389–394.

(2) Akesson, N. B., and Harvey, W. A. 1948. Chemical weed control equipment. Calif. Agric. Exp. Stn. Circ. 389, 49 pp.

(3) ———, and Yates, W. E. 1964. Problems relating to application of agricultural chemicals and resulting drift residues. Annu. Rev. Entomol. 9: 285–318.

(4) Arai, M., and Miyahara, M. 1962. Physiological and ecological studies on barnyardgrass. Proc. Crop Sci. Soc. Jap. 31(1): 73–77.

(5) ———, and Miyahara, M. 1962. Physiological and ecological studies on barnyardgrass. Proc. Crop Sci. Soc. Jap. 31(2): 186–189.

(6) Association of Official Seed Certifying Agencies. 1971. AOSCA handbook of certification. Publ. 23, 186 pp. [Looseleaf; updated periodically.]

(7) Barton, L. V. 1962. The germination of weed seeds. Weeds 10(3): 174–182.

(8) Behrens, R., Hall, W. C., and Fisher, C. E. 1955. Field responses of cotton to four phenoxy-type herbicides. Proc. South. Weed Conf. 8: 72–75.

(9) Boerema, E. B. 1963. Control of barnyardgrass in rice in the Murrumbidgie irrigation area, using 3',4'-dichloropropionanilide. Aust. J. Exp. Agric. Anim. Husb. 3: 333–337.

(10) Bohmont, D. W. 1953. Weeds of Wyoming. Wyo. Agric. Exp. Stn. Bull. 325, 160 pp.

(11) Bowling, C. C., and Flinchum, W. T. 1968. Interaction of propanil with insecticides applied as seed treatments on rice. J. Econ. Entomol. 61: 67–69.

(12) ———, and Hudgins, H. R. 1964. Compatibility of insecticides with the herbicide propanil as spray applications on rice. Tex. Agric. Exp. Stn. Prog. Rep. 2302, 3 pp.

(13) ———, and Hudgins, H. R. 1966. The effect of insecticides on selectivity of propanil on rice. Weeds 14: 94–95.

(14) Brandes, G. A. 1962. Stam F–34 proved successful for grass and weed control in rice. Rice J. 65(1): 8, 10, 12, 37–39.

(15) ———. 1963. A progress report on Stam F–34 for grass and weed control in rice. Rice J. 66(1): 6–11.

(16) Brooks, F. A. 1947. The drifting of poisonous dusts applied by airplanes and land rigs. J. Agric. Eng. 28: 233–239.

(17) Carrier, Lyman. 1917. The identification of grasses by their vegetative characters. U.S. Dep. Agric. Bull. 461, 30 pp.

(18) Chang, W. L. 1965. Comparative study of weed control methods in rice. J. Taiwan Agric. Res. 14(1): 1–14.

(19) Chem, T. M., Seaman, D. E., and Ashton, F. M. 1968. Herbicidal action of molinate in barnyardgrass and rice. Weed Sci. 16: 28–31.

(20) Coleman, P. G., Haynes, D. W. M., and Hitchcock, J. L. B. 1956. Observations on the control of weeds in padi fields by the use of herbicides. Malay. Agric. J. 39(3): 191–199.

(21) Correll, D. S., and Johnston, M. C. 1970. Manual of the vascular plants of Texas. 1881 pp. Texas Research Foundation, Renner, Tex.

(22) Crafts, A. S. 1961. The chemistry and mode of action of herbicides. 269 pp. Interscience Publishers, New York and London.

(23) Davis, L. L. 1950. California rice production. Calif. Agric. Ext. Serv. Circ. 163, 56 pp.

(24) Davis, W. C. 1954. Responses of rice to some herbicides. Tex. Agric. Exp. Stn. Prog. Rep. 1678, 4 pp.

(25) ———. 1954. Weed investigations. Proc. Rice Tech. Comm. 6: 19–21.

(26) ———. 1955. Weed killers and rice. Tex. Agric. Exp. Stn. Prog. Rep. 1812, 4 pp.

(27) Day, B. E., Johnson, E., and Dewlen, L. J. 1959. Volatility of herbicides under field conditions. Hilgardia 28(11): 255–267.

(28) Daniel, J. T., Templeton, G. E., Smith, R. J., Jr., and Fox, W. T. 1973. Biological control of northern jointvetch in rice with an endemic fungal disease. Weed Sci. 21: 303–307.

(29) De Datta, S. K., Moomaw, J. C., and Bantilan, R. T. 1969. Effects of varietal type, method of planting, and nitrogen level on competition between rice and weeds. Proc. Asian-Pacific Weed Control Interchange 2: 50–59.

(30) ———, Park, J. K., and Hawes, J. E. 1968. Granular herbicides for controlling grasses and other weeds in transplanted rice. Int. Rice Comm. Newsl. 17(4): 21–29.

(31) De La Fuente, R. K., Fertig, S. N., and Llena, P. A. 1956. The effect of two herbicides on rice plants sprayed at different stages of growth. Philipp. Agric. 40(7): 352–360.

(32) Dunham, R. S. 1965. Herbicide manual for non-cropland weeds. U.S. Dep. Agric. Agric. Handb. 269, 90 pp.

(33) Dunshee, C. F. 1928. Rice experiments in Sacramento Valley, 1922–1927. Calif. Agric. Exp. Stn. Bull. 454, 16 pp.

(34) Edwards, F. E. 1957. Sprayers for weed control improved. Miss. Farm Res. 20(4): 7.

(35) El-Refae, A. R., and Mowafy, M. 1973. Interaction of propanil with insecticides absorbed from soils and translocated into rice plants. Weed Sci. 21: 246–248.

(36) Fang, S. C. 1969. Thiolcarbamates. *In* Kearney, P. C., and Kaufman, D. D. (eds.), Degradation of Herbicides, pp. 147–164. Marcel Dekker, Inc., New York.

(37) Fernald, M. L. 1950. Gray's manual of botany. 1632 pp. American Book Co., New York.

(38) Frear, D. S., and Still, G. G. 1968. The metabolism of 3,4-dichloropropionanilide in plants. Partial purification and properties of an aryl acylamidase from rice. Phytochemistry 7: 913–920.

(39) French, G. W., and Gay, W. B. 1963. Weed control in rice fields. World Crops 15(5): 196–199, 201–204, 206.

(40) Finfrock, D. C., Viste, K. L., Harvey, W. A., and Miller, M. D. 1958. Weed control in rice. Calif. Agric. Ext. Serv. Leafl. 97, 2 pp.

(41) Georgia, A. E. 1930. Manual of weeds, 593 pp. The MacMillan Co., New York.

(42) Gifford, J. R., Oliver, B. F., Steelman, C. D., and Trahan, G. B. 1970. Rice water weevil and its control. Rice J. 73(4): 5–10.

(43) Gleason, H. A. 1952. The new Britton and Brown illustrated flora of the Northeastern United States and adjacent Canada. 3 vols. Lancaster Press, Inc., Lancaster, Pa.

(44) Goodman, V. H., Ennis, W. B., Jr., and Palmer, R. D. 1955. Cotton responses to 2,4-D, 2,4,5-T, MCP and related growth regulators. Proc. South. Weed Conf. 8: 76–81.

(45) Grist, D. H. 1965. Rice. 4th ed., 548 pp. Longmans, Green and Co., Ltd., London.

(46) Hall, Vernon, Bryan, Billy, Engler, Kyle, and others. 1963. Plastic levees in rice irrigation. Ark. Farm Res. 12(1): 4.

(47) Hall, V. L., Sims, J. L., and Johnston, T. H. 1968. Timing of nitrogen fertilization of rice. II. Culm elongation as a guide to optimum timing of applications near midseason. Agron. J. 60: 450–453.

(48) Heikes, P. E. 1959. Weed control equipment. Mont. State Coll. Ext. Bull. 300, 24 pp.

(49) Hitchcock, A. S. 1950. Manual of the grasses of the United States. 2d ed., rev. by Agnes Chase. U.S. Dep. Agric. Misc. Publ. 200, 1051 pp.

(50) Hodgson, R. H. 1971. Influence of environment on metabolism of propanil in rice. Weed Sci. 19: 501–507.

(51) Hudgins, H. R. 1961. Chemical control of barnyardgrass in the Texas rice belt. Proc. South. Weed Conf. 14: 107–110.

(52) ———. 1962. Control of barnyardgrass in rice with DPA. Tex. Agric. Exp. Stn. Prog. Rep. 2229, 4 pp.

(53) Hurst, H. R. 1970. Weeds common to row crops in Arkansas. Ark. Coop. Ext. Serv. Misc. Publ. 120, 18 pp.

(54) ———, Huey, B. A., and Smith, R. J., Jr. 1973. Weeds of Arkansas rice fields. Ark. Coop. Ext. Serv. Misc. Publ. 139, 20 pp.

(55) Johnston, T. H., Templeton, G. E., Webb, B. D., and others. 1967. Performance in Arkansas of Starbonnet and other long-grain varieties, 1962–1966. Ark. Agric. Exp. Stn. Rep. Ser. 160, 25 pp.

(56) Jones, J. W. 1926. Experiments in rice culture at the Biggs Rice Field Station in California. U.S. Dep. Agric. Bull. 1387, 39 pp.

(57) ———. 1933. Effect of depth of submergence on the control of barnyardgrass and yield of rice grown in pots. Am. Soc. Agron. J. 25(9): 578–583.

(58) ———, Davis, L. L., and Williams, A. H. 1950. Rice culture in California. U.S. Dep. Agric. Farmers' Bull. 2022, 32 pp.

(59) ———, Dockins, J. O., Walker, R. K., and Davis, W. C. 1952. Rice production in the Southern States. U.S. Dep. Agric. Farmers' Bull. 2043, 36 pp.

(60) Kapp, L. C., and Bartholomew, R. P. 1947. The effect of controlling weeds by irrigation and seeding practices on rice yields. Ark. Agric. Exp. Stn. Bull. 467, 7 pp.

(61) Kaufman, P. B. 1953. Gross morphological responses of the rice plant to 2,4-D. Weeds 2(4): 223–255.

(62) ———. 1955. Histological responses of the rice plant (*Oryza sativa*) to 2,4-D. Am. J. Bot. 42(7): 649–659.

(63) ———, and Crafts, A. S. 1956. Response of the rice plant to different formulations and methods of application of 2,4-D, MCPA, and 2,4,5-T. Hilgardia 24: 411–453.

(64) Kearney, P. C., Nash, R. G., and Isensee, A. R. 1969. Persistence of pesticide residues in soils. *In* Miller, M. W., and Berg, G. G. (eds.), Chemical Fallout, pp. 54–67. Charles C. Thomas Publisher, Springfield, Ill.

(65) ———, Smith, R. J., Jr., Plummer, J. R., and Girardia, F. S. 1970. Propanil and TCAB residues in rice soils. Weed Sci. 18: 464–466.

(66) Kim, D. S. 1969. An introduction to weed control in rice in Korea. Proc. 2d Asian-Pacific Weed Control Interchange, pp. 34–42.

(67) Klingman, G. C. 1961. Weed control: as a science. 421 pp. John Wiley & Sons, Inc., New York and London.

(68) Klingman, D. L., and Shaw, W. C. 1971. Using phenoxy herbicides effectively. Rev. ed. U.S. Dep. Agric. Farmers' Bull. 2183, 24 pp.

(69) Lancaster, J. L., Jr. 1965. Control of mosquitoes in rice fields. Ark. Farm Res. 14(5): 12.

(70) Lewis, D. C., Scott, V. H., Mueller, K. E., and others. 1962. New rice levee concepts. Rice J. 65(4): 6–15.

(71) McRae, D. H., Wilson, H. F., and Satterthwaite, S. T. 1961. The response of rice and weeds to 3',4'-dichloropropionanilide and to related anilides. Proc. South. Weed Conf. 14: 321–324.

(72) Martin, A. C., Erickson, R. C., and Stennis, J. H. 1957. Improving duck marshes by weed control. Rev. ed. U.S. Fish Wildl. Serv. Circ. 19, 60 pp.

(73) Matsubayashi, M., Ito, R., Nomoto, T., and others (compilers). 1963. Theory and practice of growing rice. 502 pp. Fuji Publishing Co., Ltd., Tokyo.

(74) Matsunaka, S. 1968. Propanil hydrolysis: inhibition of rice plants by insecticides. Science 160: 1360–1361.

(75) ———. 1969. Selectivity mechanisms of herbicides. Proc. 2d Asian-Pacific Weed Control Interchange, pp. 198–207.

(76) ———. 1970. Weed control in rice. *In* Technical Papers of the FAO International Conference on Weed Control, pp. 7–23. Weed Science Society of America, Urbana, Ill.

(77) Miller, J. H. 1963. Response of cotton to 2,4-D and related phenoxy herbicides. U.S. Dep. Agric. Tech. Bull. 1289, 28 pp.

(78) Mueller, K. E., and Oelke, E. A. 1965. Watergrass control in rice fields with propanil and Ordram. Calif. Agric. 19(7): 10–12.

(79) Muzik, T. J. 1970. Weed biology and control. 273 pp. McGraw-Hill Book Co., New York.

(80) National Academy of Sciences. 1968. Weed control. 471 pp. Washington, D.C.

(81) Neff, J. A., and Meanley, Brooke. 1957. Blackbirds and the Arkansas rice crop. Ark. Agric. Exp. Stn. Bull. 584, 89 pp.

(82) Nelson, Martin. 1944. Rotation, cultural, and irrigation practices affecting rice production. Ark. Agric. Exp. Stn. Bull. 445, 45 pp.

(83) Noda, K., Ozawa, K., and Ibasaki, K. 1968. Studies on the damage of rice plants due to weed competition (effect of barnyardgrass competition on growth, yield, and some ecophysiological aspects of rice plants). Bull. Kyushu Agric. Exp. Stn. 13: 345–367.

(84) Odglen, G. E., and Warren, L. O. 1962. The rice stink bug, *Oebalus pugnax* F., in Arkansas. Ark. Agric. Exp. Stn. Rep. Ser. 107, 24 pp.

(85) Oelke, E. A. 1966. Water depth and rice yields. Rice J. 69(7): 69–70.

(86) ———, and Morse, M. D. 1968. Propanil and molinate for control of barnyardgrass in water-seeded rice. Weed Sci. 16: 235–239.

(87) Olsen, K. L. 1957. "Scum" control in rice fields and irrigation canals. Ark. Agric. Exp. Stn. Rep. Ser. 69, 20 pp.

(88) Phillips, P. J., and Morrow, J. 1963. An evaluation of high viscosity, crowded phase emulsions as herbicide carriers when applied through the bifluid spray system. Southwest Agric. Inst. Prog. Rep. Sp-7b, 88 pp.

(89) Place, G. A. 1969. Relationship of iron, manganese, and bicarbonate to chlorosis of rice grown on calcareous soil. Ark. Agric. Exp. Stn. Rep. Ser. 175, 21 pp.

(90) Pohl, R. W. 1954. How to know the grasses. 192 pp. W. C. Brown Co., Dubuque, Iowa.

(91) Porter, W. K., Jr., Thomas, C. H., and Baker, J. B. 1959. A three-year study of the effect of some phenoxy herbicides on cotton. Weeds 7: 341–348.

(92) Prince, A. H. 1927. Weeds and grasses in Arkansas rice fields. Ark. Agric. Ext. Serv. Circ. 253, 12 pp.

(93) Robbins, W. W., Crafts, A. S., and Raynor, R. N. 1952. Weed control. 503 pp. McGraw-Hill Book Co., Inc., New York and London.

(94) Scott, V. H., Lewis, D. C., Fox, D. R., and Babb, A. F. 1961. Plastic levees for rice irrigation. Calif. Agric. 15(11): 8–9.

(95) Sierra, J. N. 1957. Effects of herbicides on weed species in lowland and upland rice fields. Philipp. Agric. 41(3): 171–190.

(96) Sims, J. L., Hall, V. L., and Johnston, T. H. 1967. Timing of N fertilization. I. Effect of applications near midseason on varietal performance. Agron. J. 59: 63–66.

(97) Slife, F. W., Buchholtz, K. P., and Kommedahl, T. 1960. Weeds of the North Central States. Rev. ed. Ill. Agric. Exp. Stn. Circ. 718, 262 pp.

(98) Small, J. K. 1933. Manual of the southeastern flora. 1554 pp. University of North Carolina Press, Chapel Hill.

(99) Smith, R. J., Jr. 1956. Weed control in rice in the Southern United States. Proc. Rice Tech. Working Group 7: 18–20.

(100) ———. 1958. The differential varietal responses of rice to 2,4-D as influenced by the stage of growth and rate of application. Rice J. 61(10): 18–19, 26–27.

(101) ———. 1960. Chemical control of barnyardgrass in rice. Weeds 8(2): 256–267.

(102) ———. 1960. Nitrogen management in rice infested with barnyardgrass. Ark. Farm Res. 9(1): 2.

(103) ———. 1960. 3,4-Dichloropropionanilide: a promising new herbicide for control of barnyardgrass in rice. Proc. South. Weed Conf. 13: 245–247.

(104) ———. 1961. Controlling barnyardgrass in rice with 3,4-dichloropropionanilide. Proc. South. Weed Conf. 14: 104–106.

(105) ———. 1961. 3,4-Dichloropropionanilide for control of barnyardgrass in rice. Weeds 9(2): 318–322.

(106) ———. 1965. Effect of chlorophenoxy herbicides on soybeans. Weeds 13: 168–169.

(107) ———. 1967. Weed control in rice in the United States. Proc. 1st Asian-Pacific Weed Control Interchange, pp. 67–73.

(108) ———. 1968. Control of grass and other weeds

in rice with several herbicides. Ark. Agric. Exp. Stn. Rep. Ser. 167, 38 pp.
(109) ———. 1968. Weed competition in rice. Weed Sci. 16: 252–254.
(110) ———. 1969. International cooperative experiments on evaluating herbicides for weed control in rice. Int. Rice Comm. Newsl. 18(3): 7–20.
(111) ———. 1969. Progress report of weed control in rice. Rice J. 72(7): 46, 85, 86.
(112) ———. 1970. Molinate for barnyardgrass control in rice. Weed Sci. 18: 467–469.
(113) ———. 1970. Systems for weed control in rice. Rice J. 73(4): 11–12, 14, 15, 18.
(114) ———. 1970. Weed control methods, losses and cost due to weeds, and benefits of weed control in rice. *In* Technical Papers of the FAO International Conference on Weed Control, pp. 24–37. Weed Science Society of America, Urbana, Ill.
(115) ———. 1971. Molinate and water management for weed control in rice. Weed Sci. 19: 196–199.
(116) ———. 1973. International cooperative experiments on evaluating herbicides for weed control in rice. Int. Rice Comm. Newsl. 22(4): 1–23.
(117) ———. 1974. Competition of barnyardgrass with rice cultivars. Weed Sci. 22: 423–426.
(118) ———. 1974. Propanil and adjuvants for barnyardgrass control in rice. Weed Sci. 22: 419–422.
(119) ———. 1974. Responses of rice to postemergence treatments of propanil. Weed Sci. 22: 563–568.
(120) ———, and Caviness, C. E. 1973. Differential responses of soybean cultivars to propanil. Weed Sci. 21: 279–281.
(121) ———, Daniel, J. T., Fox, W. T., and Templeton, G. E. 1973. Distribution in Arkansas of a fungus disease used for bio-control of northern jointvetch in rice. Plant Dis. Rep. 57(8): 695–697.
(122) ———, and Fox, W. T. 1971. Progress report of weed control in rice. Rice J. 74(6): 35–37.
(123) ———, and Fox, W. T. 1973. Soil, water and growth of rice and weeds. Weed Sci. 21: 61–63.
(124) ———, and Frans, R. E. 1969. Herbicide management in rice and soybean rotations. Abstr. Weed Sci. Soc. Am. (1969 meeting), Abstr. No. 21.
(125) ———, and Mullins, Troy. 1973. Comparative performance and economics of herbicide treatments for weed control in rice. Ark. Agric. Exp. Stn. Rep. Ser. 206, 15 pp.
(126) ———, and Shaw, W. C. 1966. Weeds and their control in rice production. U.S. Dep. Agric. Agric. Handb. 292, 64 pp.
(127) ———, and Tugwell, N. P. 1975. Propanil-carbofuran interaction in rice. Weed Sci. 23: 176–178.
(128) ———, Viste, K. L., and Shaw, W. C. 1959. Progress in weed control in rice production in the United States. Int. Rice. Comm. Newsl. 8(3): 1–6.
(129) Still, G. G. 1968. Metabolic fate of 3,4-dichloropropionanilide in plants: the metabolism of the propionic acid moiety. Plant Physiol. 43: 543–546.
(130) ———. 1968. Metabolism of 3,4-dichloropropionanilide in plants: the metabolic fate of the 3,4-dichloroaniline moiety. Science 159: 992–993.
(131) ———. 1969. 3,4,3',4'-Tetrachloroazobenzene: its translocation and metabolism in rice plants. Weed Res. 9: 211–217.
(132) ———, and Mansager, E. R. 1969. The presence of 3,4-dichloroaniline in rice grain hydrolysates. Weed Res. 9: 218–223.
(133) Takematsu, T., and Yanagishima, S. 1963. Studies on the herbicidal phenomenon and the function of dichloropropionanilide a weed killer having a selective herbicidal effect on genera of Gramineae. Il Riso 12(3): 37–70.
(134) U.S. Agricultural Research Service. 1965. A survey of extent and cost of weed control and specific weed problems. U.S. Dep. Agric., Agric. Res. Serv. [Rep.] ARS 34–23–1, 78 pp.
(135) ———. 1965. Losses in agriculture. U.S. Dep. Agric., Agric. Handb. 291, 120 pp.
(136) ———. 1968. Extent and cost of weed control with herbicides and an evaluation of important weeds, 1965. [Rep.] ARS 34–102, 85 pp.
(137) ———. 1970. Selected weeds in the United States. U.S. Dep. Agric., Agric. Handb. 366, 463 pp.
(138) ———. 1972. Extent and cost of weed control with herbicides and an evaluation of important weeds, 1968. U.S. Dep. Agric., Agric. Res. Serv. [Rep.] ARS–H–1, 227 pp.
(139) ———. 1973. Rice in the United States: varieties and production. U.S. Dep. Agric., Agric. Handb. 289, 154 pp.
(140) U.S. Department of Agriculture. 1973. Agricultural statistics, 1973. 617 pp.
(141) U.S. Economic Research Service. 1974. Rice situation. U.S. Dep. Agric., Econ. Res. Serv. [Rep.] RS–23, 24 pp.
(142) Velasco, J. R., Vega, M. R., and Llena, P. A. 1958. Effects of repeated herbicide spraying on upland rice. Philipp. Agric. 41(8): 432–439.
(143) Viste, K. L. 1963. Control of weeds in rice in California. Proc. Rice Tech. Working Group 10: 10–11.
(144) ———, and Finfrock, D. C. 1958. Factors influencing herbicidal injury to rice. Proc. Rice Tech. Working Group 8: 9–12.
(145) Weed Society of America. 1974. Herbicide handbook. 3d. ed. 430 pp.

(146) Weldon, L. W., Blackburn, R. D., and Harrison, D. S. 1969. Common aquatic weeds. U.S. Dep. Agric., Agric. Handb. 352, 43 pp.

(147) Williams, R. E. 1955, 1956. Weeds in rice [in 11 parts]. Rice J. 58(13) : 18–19; 59(1) : 8–9; (2) : 8; (3) : 8–9; (4) : 14; (5) : 24; (6) : 34–35; (8) : 22–23; (9) : 15; (10) : 16–17; (12) : 20–26, 28.

(148) Wooten, O. B., and Holstun, J. T., Jr. 1959. Special equipment for chemical weed control. Miss. Agric. Exp. Stn. Bull. 576, 16 pp.

(149) Yamada, N. 1966. Recent advances in chemical control of weeds in Japan. Int. Rice Comm. Newsl. 15(2) : 1–5.

(150) Yih, R. Y., McRae, D. H., and Wilson, H. F. 1968. Mechanism of selective action of 3',4'-dichloropropionanilide. Plant Physiol. 43: 1291–1296.

(151) ———, McRae, D. H., and Wilson, H. F. 1968. Metabolism of 3',4'-dichloropropionanilide: 3,4-dichloroaniline-lignin complex in rice plants. Science 161: 376–377.

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